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ABSTRACT

Perspectives on issues affecting manufacturing enterprises are given by educators and industrial planners and managers in this symposium report. The symposium was designed to bring together industrial manufacturing companies and the universities which are responsible for educating those who will plan and operate manufacturing systems. Working groups were formed to identify issues and recommend actions for those in the public and private sectors responsible for ensuring the match between educational institutions and the needs of industry. The symposium's presentations and papers are organized in the report in three sections. These include: (1) papers (examining the engineer, the changed face of manufacturing and education and industrial needs); (2) a panel discussion (containing presentations on corporate attitudes toward introducing new manufacturing technology); and (3) working group reports (addressing concerns in structuring the manufacturing education system, industry-university cooperation in education and research, manufacturing careers and priorities in manufacturing education). Appendices include a register of symposium participants, a selected bibliography and a statement of the purpose of the symposium. (ML)

Education for the Manufacturing World of the Future

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Series on Technology
and Social Priorities

NATIONAL ACADEMY
OF ENGINEERING

Education for the Manufacturing World of the Future

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The National Academy of Engineering is a private organization established in 1964. It shares in the responsibility given the National Academy of Sciences under a congressional charter granted in 1863 to advise the federal government on questions of science and technology. This collaboration is implemented through the National Research Council. The National Academy of Engineering recognizes distinguished engineers, sponsors engineering programs aimed at meeting national needs, and encourages education and research.

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Preface

The manufacturing world of the future is evolving piecemeal—on the factory floor, in robotics research laboratories, in computer and information systems development groups, and among manufacturing systems task groups in industry. At stake is the future industrial competitiveness of this nation. Our competitiveness will depend on increasing the productivity of manufacturing systems in all industries and on our ability to transform multifaceted manufacturing functions into cohesive, flexible systems using the new technologies spawned by the electronics and materials revolution. Competitiveness will also depend on achieving product quality and lowering production costs. Fortunately, the new technologies put these goals within grasp.

The changes taking place in industry as manufacturing adopts and adapts to new processes aimed at increased productivity are paralleled by new views of the educational system and of the training received by engineers and other specialists who will plan, implement, and operate the new automated manufacturing systems. The ferment occurring in the world of manufacturing is matched by that found in engineering schools as new curricula and new approaches to engineering education are pioneered.

PURPOSE OF THE SYMPOSIUM

The Symposium on Education for the Manufacturing World of the Future was convened by the National Academy of Engineering (NAE) in cooperation with the Manufacturing Studies Board of the National Research Council, and it was intended to bring together the two communities essential to national success in manufacturing. These communities include, on the one hand, industrial companies affected

by the changing manufacturing scene and those responsible for developing the technologies that underpin automated manufacturing, and, on the other hand, the university community responsible for the education and training of students who will plan and operate these manufacturing systems.

The symposium provided an opportunity for both industrial planners and managers and educators to examine the issues whose resolution will greatly affect the changing world of manufacturing. We wished to hear industry's views of the requirements for educating and training engineers by our universities and about cooperative endeavors with academic groups and other mutually beneficial relations. We sought from the academic community their plans for training and educating engineers for manufacturing careers and their views of possible cooperative arrangements with industry.

Symposium participants were organized into working groups that covered five related topics:

1. Structuring the Manufacturing Education System
2. Industry-University Cooperation in Education for Manufacturing
3. Industry-University Cooperation in Research for Manufacturing
4. Keeping Current in a Manufacturing Career
5. National Priorities in Manufacturing Education

These working groups sought to identify issues and to recommend actions for those in the public and private sectors responsible for ensuring the match between educational institutions and those who need their products.

This volume comprises the papers presented as basic documentation for symposium participants (Part 1), presentations by participants in a panel discussion on corporate attitudes toward introducing the new manufacturing technology (Part 2), reports of the discussions held by working groups (Part 3), and an excellent statement of the problem, which in part stimulated the convening of the symposium, by the Manufacturing Studies Board of the National Research Council (Appendix A). The selected bibliography appearing in Appendix B will help readers locate the disparate literature that relates to issues addressed in the symposium. Finally, a register of symposium participants, who generously donated their time and energy, and a list of the working groups are provided in Appendix C.

The symposium's novel form was devised by its cochairmen Dr. Robert A. Frosch, vice-president for research of General Motors Corporation, and Mr. Erich Bloch, who was at the time of planning for the symposium vice-president for technical personnel development

at the IBM Corporation. Mr. Bloch is currently director of the National Science Foundation. The session was organized largely by Ms. Lissa Martinez, a National Academy of Engineering fellow and engineering graduate of the Massachusetts Institute of Technology on leave from the U.S. Maritime Administration.

The assistance of a large number of staff members of the National Academy of Engineering and the National Research Council was essential to the success of the symposium. Our appreciation is extended to Jesse H. Ausubel, Bruce Guile, Hugh H. Miller, and Penny Gibbs of the NAE staff; to George H. Kuper, George D. Krumbhaar, Janice E. Greene, and Donna L. Reifsnider of the Manufacturing Studies Board; and to Sabra Bissette Ledent, the report's editor.

This symposium was the first in a series on technology and social priorities convened by the National Academy of Engineering. The series is supported by funding from the Andrew W. Mellon Foundation, the Carnegie Corporation of New York, and the Academy Industry Program. The views expressed in this volume are those of the authors and of the meeting participants. They are not presented as the views of the Mellon Foundation, the Carnegie Corporation, the Academy Industry Program, or the National Academy of Engineering.

ROBERT M. WHITE
President
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* Mr. Bloch served as cochairman of the advisory committee until September 1984 when he became director of the National Science Foundation.

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Manufacturing and Education: Reflections on a Symposium

ROBERT A. FROSCH

Following are this cochairman's observations and reflections on the Symposium on Education for the Manufacturing World of the Future convened by the National Academy of Engineering. While not a summary of the proceedings in a strict sense, these remarks attempt to capture the tone of the meeting that emerged in both formal and informal discussions among the participants, and highlight some of the major points expressed, suggested, and recommended by individual participants and working groups.

From the outset, symposium participants appeared to be clearly frustrated about the state of manufacturing engineering and the status of manufacturing engineers. Apparently a major source of this frustration is a distinct (and probably correct) perception that the importance of manufacturing in the process of innovation and in the establishment of business competitiveness has been almost completely ignored for a long time. With the focus of business attention on fiscal and management areas, the art and science of manufacturing engineering have been allowed to decay, and companies have not recognized manufacturing engineering skills as high-priority ones to be highly rewarded. Rather, manufacturing has increasingly become a place to demonstrate only "managerial" skills, with more rewards given for these than for technical competence, skill, and ingenuity in the technical tasks of

Robert A. Frosch served as cochairman of this symposium with Erich Bloch, who served until September 1984.

manufacturing. In fact, manufacturing jobs have increasingly become routes to other parts of the business and to expanding responsibility in nonmanufacturing areas.

In spite of the considerable talk about the importance of manufacturing engineering, participants felt that relatively little change has occurred during the past several years in the status of manufacturing engineers in corporations, and that the status of manufacturing engineering is only beginning to change within the academic community. Indeed, another theme clearly expressed at the symposium was a good deal of uncertainty about what direction this change should take.

There was also considerable uncertainty about what a manufacturing engineer is in terms of education and training, as well as the nature of manufacturing and engineering and the skills and ideas involved. This is quite understandable given the variety of activities undertaken in manufacturing and the variety of products involved. It is not immediately obvious that a homogeneous discipline even exists, making it extraordinarily difficult to describe a definite curriculum that should be pursued.

All of this is intensified by the fact that manufacturing has not been highly regarded as a career path for students because of its curious position in industry. The best students in engineering rarely choose to take manufacturing-related courses, even when they are available. Instead, they choose the much more popularly regarded courses such as computers and communication. In the areas of engineering most closely connected to manufacturing—the structural and dynamics aspects of mechanical engineering, for example—there has been a tendency toward theoretical curricula little related to manufacturing processes. In the view of the participants, all this appears to have been exaggerated by the relatively little contact between the academic world and the world of manufacturing. There has been much talk about closer contacts between these two worlds, but the process seems to be only beginning.

DILEMMAS AND CONNECTIONS

In the discussions of several working groups, as well as in the speeches and panel discussion, conflicts arose regarding the idea of theory and the matter of the reality of the manufacturing floor. It was stated that experience, not theory, is the key to solving problems, and yet a grounding in fundamentals is extremely important.

To complicate the matter further, the view was expressed that part of the problem stems from the lack of a good body of theory about

manufacturing and manufacturing engineering, making it difficult to construct a curriculum and educational program. This is the case, and it results partly from the problem of how to define a manufacturing engineer, as well as how to answer the question: What body of theory can be constructed for what is not yet defined as a coherent body of experience and operation?

One theme touched upon several times in the discussion—the dichotomy or balance between the engineering and nonengineering problems of manufacturing—may help illuminate the question of theory. Engineering problems describe engineering in the strictest sense: the physical nature of machines, the processes by which machines create a product, the engineering systems that provide the physical designs for machines and processes and control the machines, and the means by which materials are moved and controlled.

Nonengineering problems concern the need to put the engineering side of manufacturing in an overall business context, so that engineering choices make economic sense and relate properly to social questions of health, environment, and the position and relationships of labor, management, and machines. Both speakers and discussants pointed out that a purely technical education in the traditional engineering sense is insufficient for a manufacturing engineer, since so much of his or her effort deals with the business and social systems making the manufacturing system work.

Thus while it was generally agreed that the manufacturing engineer needs a background in social and economic systems and that the engineering manager—the business manager—needs a background in production skills, it was also generally agreed that both parties are likely to suffer from an attempt to cover both curriculum areas. In a related viewpoint, several participants pointed out the inadequacy of the economic and accounting tools necessary for manufacturing and suggested that a new system be developed.

Thus a view emerged in both the presentations and discussion that a much closer connection is needed between the technical engineering side and the business management side of education for manufacturing. However, dissatisfaction was also expressed with the existing base of knowledge, and hence curriculum, for both sides. The latter view leads to a clear implication for research on the systems aspects of manufacturing, as well as on the individual engineering techniques that go into processes. On the business side, research is needed on new business systems for understanding and controlling the economics and management aspects of manufacturing systems.

All these viewpoints suggest the importance of establishing connections between business and engineering schools within universities so

that each can bolster the curriculum of the other in preparing engineers and managers for manufacturing. These connections should clearly extend beyond concerns with curricula to the research necessary to establish a better set of foundations for future manufacturing engineering and management. Both the engineers and business managers emerging from such coupled curricula would be better prepared not only for their roles in manufacturing, but also for moving, in a career sense, beyond manufacturing to management roles in the total manufacturing business.

In stressing another connection, representatives of both academia and industry agreed that the mechanisms used by students and faculty to obtain knowledge of the manufacturing reality and to construct and teach a theory based on that reality, respectively, were inadequate. They also recognized the inadequate understanding that industry people have of the educational process and of the opportunities to influence that process.

Both parties are eagerly seeking answers to these inadequacies, but the clear mismatches between the practices and arrangements in the two sectors make this no easy task. For example, the time pressures and economic realities facing industry do not allow engineers to spend much time in academia, and their experience does not substitute for the criteria that would make them acceptable in academic circles. Conversely, the theoretical backgrounds of academics are not considered sufficient for them to play continual direct roles in the industrial context, and they too have time difficulties in arranging this. Clearly, considerably more discussion and a greater number of experiments in industry-academia cooperation are needed to find better ways to resolve these difficulties.

Thus the construction of new understanding and of a new curriculum for manufacturing engineering education must be seen in the context of a three-body institutional problem; the engineering and business schools of academia and industrial manufacturing. Indeed, the connections between industry and the university community must include both the engineering and business schools, and these connections may play a role in which these two academic forces work together effectively to produce new systems understanding and methods for manufacturing.

VALUE OF THE MEETING

This symposium was a meeting ground for the three communities just described. While principally a meeting of engineers interested in manufacturing engineering, the symposium also included participants

who understood the business school aspect of the problem from both the industrial and the academic sides. In particular, it gave representatives of the manufacturing sector an opportunity to meet together.

This new opportunity for many of the participants to discuss what turned out to be common subjects was the key value of the symposium. New and continuing opportunities for such interaction will be important to improve the currently inadequate arrangements for contacts between industry and academia related to this subject and to upgrade common contributions toward research and toward common understanding of suitable curricula.

CONCLUSIONS AND RECOMMENDATIONS

Participants in this symposium thus concluded that some specific problems must be attacked, although they did not define these problems in great detail. Problems center on attempts to provide a theoretical substructure for the system aspects of manufacturing engineering and the need to establish new bases and new systems for the business aspects of manufacturing engineering.

These findings should not be interpreted as the feeling that there is no useful existing material. Rather, it is not clear how to bring what exists into a modern context and provide a suitable foundation for new manufacturing technologies, particularly the computer and robotic revolution which seems about to overtake manufacturing. Any new approaches must, however, involve industry, engineering schools, and business schools, either on individual bases or in whole university and industry contexts.

These general conclusions suggest a number of potential activities. First, discussion and contacts are needed between industry and individual companies and the universities in their areas, or with whom they work, to reach agreement on a suitable forum for examination of these issues. Second, academics and those in industry should keep each other in mind and, by issuing invitations to appropriate events, continue and enrich their contacts. Third, additional symposia could be useful if they include participants from the necessary sectors and are carefully designed to attack these problems.

Meetings specifically aimed at discussing possible research agendas might be useful if they are meant to produce a set of ideas that individual schools and industries might use as material to think about and work on, not an agreed-upon agenda for group action. Such meetings could be held together or separate from meetings to discuss curricular possibilities, and they should include not only academics

but also a leavening of industry people. Furthermore, these meetings should go beyond narrowly defined gatherings on technical engineering or on business management to mix people from opposite fields.

While little was said at this symposium about the roles of professional societies in this process, they could well ponder the results of the proposed cooperation between industry and academia in considering their programs in fields related to manufacturing.

Clearly, this symposium produced results which, while not precise, suggest further activities and directions of work, and indeed, suggest actions that the National Academy of Engineering might take in planning its future program.

Part 1.
Papers

The Changing Face of U.S. Manufacturing

JOSEPH F. SHEA

How can education contribute to the revitalization of American manufacturing industry? This issue is central to the competitive position of the United States in the world economy, and to the direction in which U.S. society will evolve in the decades ahead. This paper does not dwell on how U.S. industries have become noncompetitive. Rather, it attempts to indicate what can be done, indeed, what is already being done, in many factories. There is growing evidence that much improvement is possible in the short term, and that American factories of the future can be competitive in most basic industries if national technological and management resources are harnessed.

Over the last five years, the National Academy of Engineering and the National Research Council have addressed ways to improve the competitive position of U.S. manufacturing industries. The Research Council established the Manufacturing Studies Board in 1980, and the Academy devoted its eighteenth annual meeting in November 1982 to U.S. Leadership in Manufacturing. The keynote speaker at that meeting, Professor James Brian Quinn of Dartmouth College, documented the declining competitive posture of U.S. industries in the world market and made a strong case that, as a nation, the United States cannot afford to let itself become a service economy with production limited only to high-technology products.[1] He ended by voicing a guardedly optimistic view of the future.

Joseph F. Shea is senior vice-president of engineering, Raytheon Company, Lexington, Massachusetts.

In broad terms, the solution lies in taking the following steps:

- Enhance the prestige of manufacturing as a profession and as an intellectual challenge.
- Involve, once again, the top management of our corporations in the process of production and quality.
- Break down the artificial barriers which exist in most companies between design and production.
- Treat the manufacturing process as a system, not as a collection of discrete, loosely coupled functions.
- Increase the commitment of our engineering schools to manufacturing technology.
- Increase the interaction between industry and universities in manufacturing education and research.
- Provide economic incentives from federal, state, and local governments.
- Share information on what can be and is being accomplished.

The details of implementation will vary by industry, but most of the above steps will be prerequisites for any significant improvements. Before elaborating on these points, it is useful to consider two examples which illustrate both the nature of the problem and the path to a solution.

In the first example, a defense electronics contractor improved yield from about 15 percent to over 75 percent through a complex printed circuit line, and found that the labor required for the same operation could be reduced by almost 50 percent. The stimulus for improvement came from visits to Japanese companies producing similar products, where equivalent yields were well over 90 percent, with no apparent difference in technology or tooling. Japanese management would not accept the amount of rework which had become the norm in the United States, and their workers responded by controlling in-process defects. When American management realized that they could do what others had done, the gains were dramatic.

In a second example, a major U.S. electronics company, which found itself not cost-competitive, cut the product cost of a line of displays by a factor of 2, increased inventory turns from about 5 to 50 (and expects to reach 80), and plans to use present floor space to produce 5 times the originally planned volume. The company had found that the Japanese produced an equivalent product with less than half the support labor, required fewer kinds of parts because of effective standardization, and based design of a production line on a close working relationship between design and manufacturing engi-

neers. By emulating the Japanese, the American company was competitive in less than three years.

These are not isolated instances. Examples abound in a broad range of American industries, including automotive, appliance, hand tool, and electronic companies. U.S. industry became noncompetitive because designs were not readily manufacturable and because quality standards that were much too low were tolerated in factories.

WHAT IS POSSIBLE

In many areas of engineering, one can evaluate how close a design—for example, for a combustion cycle, an amplifier, or a structure—comes to a theoretical limit. There is no such theoretical basis, however, for producibility of a design and achievable quality levels. Companies tend to set standards based on past performance of similar products and whatever they know about domestic competition. From that point of view, cost reductions or quality improvements of a few percent can seem like major accomplishments. But now there is hard empirical evidence in many sectors that much more is possible. New standards have been demonstrated, and one must note the magnitude of the improvements being discussed: factors of 2 or more in cost and factors of 10 to perhaps 100 in reject rate, which has a direct bearing on quality of the delivered product.

Much of industry has grown sluggish with past success. Achieving anew the manufacturing excellence for which America has long been known will be difficult because many managers do not start from fresh ground. They must first rid themselves of outdated assumptions, practices, and prejudices. There is evidence that the work force will respond to new management leadership, such as the success achieved in color television manufacture when Sanyo management took over the old Warwick plant with many of the same employees and U.S. middle management.

Improving the factories of today is but one more step in the continuing industrial revolution. The first phase, from the 1780s to the 1840s, was based on the application of steam power. The second phase, between 1860 and 1910, was based on new forms of power from oil and electricity. The third phase, beginning in the 1950s, was assumed to be based on nuclear energy; however, for a complex series of reasons this has not happened. Rather, this phase is based on the application of electronic systems—computers and automation—to widening areas of data handling, automation, and control.

Manufacturing is a process which transforms information into a

product. The information includes design data, quantities required, and delivery dates. The transformation involves developing tools and processes, obtaining material, processing material, assembly, testing, and delivery. The factory of the future will be an integrated system with a common engineering and manufacturing data base. Data processing will be used extensively to receive design information without having to reconfigure for manufacturing, estimate and order material, control inventory, program machines, monitor yields, and program test equipment. Automation will be extensive, encompassing material handling, numerically controlled machines, and closed-loop process control. Robots will function as welders, painters, assemblers, and inspectors.

New materials with advanced properties will displace conventional products and processes. For example, the silicon revolution in digital electronics is known to all. Monolithic gallium arsenide microwave circuits will have an equally dramatic effect in radio frequency devices over the next decade. Composite materials, including carbon fibers imbedded in resin, will change structural designs. One general aviation manufacturer has already wound a complete fuselage from carbon fiber tape in less than a day and a half.

Although the details will vary by industry, the factory of the future will challenge our long-held belief that high-volume runs of identical products are required to achieve low cost. It is conceivable that early in the next century computer-controlled flexible manufacturing systems will produce virtually all of the material goods required by society, except those with high artistic content.

The companies that master this transition will gain nearly unassailable positions in the world market through their ability to produce quality products tailored to special customer requirements on a very short lead time. As the examples cited above indicate, however, a major portion of the gains to be achieved can be realized today, not in the twenty-first century, with existing technology. One approach, well established in Japanese firms and successfully employed by several American companies to improve quality and productivity while reducing lot sizes, is the "just-in-time" production concept. This concept is based on the notion of producing only in response to customer demand and on short lead time.

Design and operation of a manufacturing plant capable of efficiently producing any and all of its products on demand and with short lead times while conforming to quality standards require:

- Plants with well-defined product lines;

- Tight pull scheduling—that is, production responsive to customer demand;
- Efficient, flexible layouts and balanced process capabilities;
- Well-developed processes operating under statistical control;
- Small lot sizes;
- High employee involvement; and
- Continuing training and investment in employees throughout their careers.

Finely focused factories were found in America in the nineteenth century. Today, they imply standardization of elements within a limited product family, close integration of product and tooling design, and discipline in design evolution to maximize the use of proven tooling and production processes. They will force a restructuring of the relationship between a manufacturer and the supporting vendors. Hewlett-Packard, among many others, is particularly well known for its work in this area.

Flexible layouts combine group technology—that is, part families funneled through a complete machining center—with production lines that enable manning in response to production demand, rapid communication among operators, and efficient material movement. Black and Decker has successfully responded to offshore competition by pioneering these concepts.

In recent years, it has been rediscovered that the defect level must be reduced to as near zero as possible for critical functional tolerances. Even acceptable quality levels of 99 percent or so will not produce cost-competitive products. The percentage of defects can and must be driven down toward the parts per million range. This requires processes capable of statistical control, with operator responsibility for self-inspection and authority to shut down the machine whenever there is evidence that it is out of control. This key to Japanese quality is being adopted in the United States, and the General Electric dishwasher plant in Louisville, Kentucky, is a good example. The Ford Motor Company has published an excellent booklet on the subject.[2]

Efficient processing of small lot sizes requires minimal set-up times. A prime example is the Toyota hood and fender plant where a line consisting of a 500-ton toggle press and three 300-ton single action presses can be set up in less than 10 minutes. Many American companies are finding that set-up times can be reduced by 90 percent or more. Four Deere & Company plants, including a foundry, and plants manufacturing diesel engines, garden tractors, and heavy farm equip-

ment have already made major gains, as has Speed Queen, one of Raytheon's subsidiaries.

Employee involvement requires developing a team authorized to control quality at the source, trained in many different operations, able to move from operation to operation as demand dictates, and able to handle all routine set-ups and maintenance as a matter of course. Such teams are the natural precursor to the technician teams required to run the factories of the future.

One example of the team approach is TRW's wire and cable plant in Lawrence, Kansas, which is operated by a semiautonomous team. Team members are encouraged to become qualified to operate every piece of equipment in the plant, for which they must pass both written and hands-on operating tests. They are then paid for the highest qualification achieved, regardless of the job duties being performed at the moment. The team follows the flow of work through the plant, operates different machines as required, and even makes decisions on manning and operation times to meet schedule requirements.

The just-in-time concept has resulted from a reexamination of the manufacturing process as a system. The gains include inventory reduction, regained floor space in the plant, shorter schedules, lower costs, and higher quality. The results achieved by a growing number of companies demonstrate what can happen by creating an intellectual climate that challenges entrenched assumptions about how manufacturing plants should be structured.

A HISTORIC VIEWPOINT

The aspects of manufacturing just discussed—flexibility, design standardization, tooling, tightly controlled tolerances, product evolution, supplier base, and quality—are not new. Ironically, they contributed to the growth of American manufacturing from the early 1800s to the present.

When Eli Whitney took a government contract in 1798 to deliver 10,000 muskets two years later, colonial manufacturing was a collection of artisans in cottage industries. Finished products varied widely in quality, and gross imperfections were common. Whitney spent a year building the tools, jigs, and other production fixtures necessary for an integrated flow of work through his factory. At each station, he located tools, machines, parts, and skilled workmen to keep the flow of muskets steady. By organizing to accommodate a regular process of manufacture, and by building machinery capable of working within

fine tolerances, Whitney redefined the nature of the production task. He pioneered the first of six stages of American manufacturing: factories well suited to the sequential production of simple, imitative, not very capital-intensive products, assembled from machine-made, interchangeable parts.

The second phase of American manufacturing began when demand for volume production of consumer goods, such as sewing machines, required that products be broken down into clusters of technologically specialized components. The latter were then assigned to different factory work units which fed them as needed into the overall process flow. Isaac Singer devoted much time and energy to product design, developed standardized components, and organized his production system as a vertically integrated whole. The 32-acre plant Singer built in 1873 had a rail-supplied foundry, forging shop, milling department, and multiple facilities for inspection and testing of both components and final products. He found, by experience, that it paid to put just as good parts into the cheapest machine as into the highest priced pearled and ornamented cabinet machine. Across the product line only the decor changed; all the working parts were the same.

Highly specialized, vertically integrated factories tended to resist model change, however. Many companies which emulated Singer fell into the trap of manufacturing a product with increasing efficiency until it became obsolete, but Samuel Colt, the legendary arms maker, confronted the issue directly. He took American manufacturing into its third stage by institutionalizing constant improvement in process and product technology as a path to achieving competitive advantage.

The central reality of the fourth stage was the new-found importance of suppliers. The end of the nineteenth century saw a rapid proliferation of machine shops, die makers, and technology base suppliers—an infrastructure which helped prepare the ground for the first generation of automobile manufacturing. The existence of this supplier base lent support to managers who were personally experienced in process technology and understood sources of components. Allan Nevins writes of Henry Leland, who supplied engines to Ford as well as to the Olds Motor Works before forming the Cadillac Motor Car Company in 1902[3]:

> To work to a 1/10,000 of an inch was not exceptional in that factory, and Henry M. Leland could supervise production requiring 1/1,000,000 of an inch. The firm had devised or improved some of the machine tools, and had worked out the revolutionary methods which produced the gears for the Columbia bicycle and other metal products combining great delicacy, strength, and precision.

During times of technological ferment like that characterizing the first few decades of the automobile industry and challenging us now, management skills and technical understanding on the order of Leland's are invaluable to competitive success.

The fifth stage resulted in the strength of our industrial capacity during and after World War II. A flow system, producing technologically complex products at high volume, was mastered. Henry Ford organized operations at Highland Park strictly in terms of the necessary flow of work by using separate production lines for each component to reduce process bottlenecks, by applying conveyors and other techniques of line-flow management, and by driving inventories down to acceptable levels. One unsolved problem was the integration of the work force into the production process—not as a faceless mechanism, but as a reservoir of competitively valuable human strengths.

U.S. industry is late coming to a sixth phase of American manufacturing, perhaps because its very success has led it to believe that it is as good as it could be. For several decades, in all too many industries, management effort has been directed away from production and toward marketing and finance. It is time to redress that neglect and reap the benefits of creative integration of a skilled labor force, data processing, and advanced technology into the production process.[4]

Plato wrote in *The Republic*: "The direction in which education starts a man will determine his future life." Accordingly, in 1984 the Manufacturing Studies Board of the National Research Council commissioned a study of industry-academia cooperation in manufacturing, recognizing that creation of an intellectual climate to carry out the changes discussed here requires that industry and universities focus together on manufacturing technology. This is easier said than done in the academic world, because many problems in manufacturing are applied research at best and may not rank high on the tenure criteria. Until manufacturing curricula are developed by universities and become an attractive option for the better students, the issues of competence of manufacturing personnel and their ability to adapt to technological opportunity will continue.

Schooling is necessary but not sufficient. Industry must change the employment practices for manufacturing professionals, and provide both financial incentives and intellectual challenges so that better candidates will opt for careers in manufacturing.

In the short run, the obvious route is for industry to encourage changes in university curricula and to supplement those changes with applied research support related to the specifics of individual industries. The issues become how to convince management that such investment

is prudent, and how to bring engineering faculty up-to-speed fast enough so that they are indeed useful in either training or consulting.

The Research Council study on university-industry cooperation in manufacturing chaired by this author has not yet finalized its recommendations, but its initial conclusions are summarized here. The study has concluded that three segments of society must work together to reinvigorate American manufacturing: industry, universities, and government. Actions appropriate to each are suggested below.

WHAT CAN INDUSTRY DO?

Management must be convinced that significant changes are possible. In the short term, quality and productivity can be improved by focusing on details within the manufacturing process. In the long term, investments in technology, both process and system, and in the people who operate that technology can result in factories of the future which retain or regain a competitive position in world markets.

Achieving these ends will require increased technical strength in manufacturing organizations. Recruiting for manufacturing will have to be put on an equal basis with engineering; manufacturing salaries will have to compete with engineering salaries; and continuing education programs must be developed for manufacturing personnel. Organizational reforms must force a closer relationship between engineering and manufacturing to develop producible designs and the restructuring of factories to reflect the systems nature of manufacturing operations. More important, manufacturers must be convinced that universities can contribute and must be willing to explore modes of cooperation. Obviously, the conviction will vary from industry to industry, with major differences from company to company within a given sector.

WHAT CAN UNIVERSITIES DO?

Manufacturing curricula must receive peer and administrative acceptance, requiring a strong champion within the institution. Universities that choose to strengthen or initiate manufacturing-related programs must define the criteria by which those efforts will be judged against more traditional research activities.

Manufacturing systems engineering curricula are being developed. There appears to be no general agreement on what the course content should be, or how it can be applied to a given industry. Examples stressing manufacturing applications should be introduced into the

core technical courses in the established disciplines. Faculty must be given release time for curriculum development.

It is hoped that the issue of curriculum content will receive reasonable attention from this symposium, particularly as related to manufacturing as a system. This topic must not be confused with courses related to manufacturing processes which should be taught within the traditional engineering school structure. The physics, chemistry, metallurgy, instrumentation, and control courses required for, say, submicron semiconductor fabrication, fiber optic communications, composite structures, and synthesis of new chemical products, are subject matter for the electrical, aeronautical, mechanical, and chemical engineering faculties.

The tougher question is how—and, frankly, whether—to teach manufacturing as a system. The traditional industrial engineering programs are not, in general, held in high esteem by either industrial or academic peer groups. Since a fundamental principle of management should be "You cannot manage that which you do not understand," a student must come to a manufacturing systems engineering (MSE) curriculum with a strong engineering foundation perhaps augmented by a year or two of industrial experience.

The seeds of a manufacturing systems curriculum may lie in providing courses which apply the principles of data processing, information systems, data base feedback and control, employee utilization and motivation, and system engineering methodology to management of a manufacturing system. Since manufacturing must work closely with design, the principles of design for manufacturability must also be included, as well as the use of automation together with cost estimating in the design cycle.

Quality must be a required subject—not just the usual principles and statistical methodology, but emphasis on what quality levels can be and have been achieved. These experiences can set the standards by which students judge the future performance of their plants.

This is a lot to pack into a degree program, and some of it may be better learned if it is deferred to continuing education. At the least, the MSE student should take away a vision of what factories can become, some tools with which he or she can begin to contribute, and the zeal to make the vision a reality.

Universities must encourage better students to consider careers in manufacturing by raising admission standards and by stressing manufacturing opportunities in high school recruiting. And, perhaps, university research can develop a stronger theoretical basis for manufacturing. What is meant by a producible design? How can achievable

quality levels be estimated? Together, industry and universities can establish research programs that address problems in manufacturing technology.

Additional actions suggested for industry and universities include:

- Financial support by industry for manufacturing initiatives at universities including grants, equipment (and related maintenance support), and scholarships;
- Joint development of co-op programs and defined research programs in manufacturing;
- Use of industry personnel as adjunct faculty; and
- Use of faculty as industrial consultants, and faculty sabbaticals in manufacturing assignments.

WHAT CAN GOVERNMENT DO?

These problems have begun to attract government attention at both the state and national levels. Several states have appropriated funds for the establishment of centers of manufacturing technology to encourage regional groups of industries and universities to focus on the generation and dissemination of knowledge in this area. The Ben Franklin Institute in Pennsylvania, the Industrial Technology Institute in Michigan, Rensselaer Polytechnic Institute's Center for Manufacturing Productivity and Technology Transfer in New York, and programs in Ohio, Arizona, North Carolina, and elsewhere are innovative and promising experiments. Proof of success will be the degree to which these centers can become self-sustaining. Industry will have to provide the necessary support by recognizing the value of services received.

Federal policy is still evolving. The Department of Defense, long a sponsor of manufacturing research, has increased funding in manufacturing-related technologies, primarily related to defense needs. The National Science Foundation sponsors a program in manufacturing sciences and is in the process of creating a series of Engineering Research Centers, several of which will relate to manufacturing. The U.S. Congress is contemplating several bills, but no clear pattern has emerged.

A broad cross section of industry must be motivated to improve manufacturing practices and to explore what help they can get from universities or the emerging manufacturing centers. Companies must be encouraged to find out what modern technology, applied to their particular situations, can do. Some form of tax incentive that promotes

cooperative programs may help align the random motions inherent in our free economy.

Today, perhaps 5 percent of engineering schools stress manufacturing, but the problem is critical enough that probably 95 percent should be offering competent programs. It must be cautioned, however, that the assumption that universities can effectively contribute to either short- or long-term improvements in manufacturing is an intellectual act of faith.

Most of the progress cited has been made in industries on the high-technology side of the national spectrum, but the actions advocated here have broader applicability. Management in many industries must be convinced that they have an alternative to low labor rate, offshore factories, or inevitable surrender to foreign competition.

NOTES

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4. This encapsulated view of American manufacturing history draws extensively on *Industrial Renaissance, Producing a Competitive Future for America* by W. Abernathy, E. Clark, and A. Kantrow of the Harvard Business School (New York: Basic Books Inc./Harper Colophon Books, 1983).

The U.S. Manufacturing Engineer: Practice, Profile, and Needs

FORREST D. BRUMMETT

The future of manufacturing will involve processes, materials, products, industries, and applications of technology that will open new markets and provide new challenges for manufacturing. Yet there is great concern that the United States no longer has the reservoir of expertise in manufacturing to take full advantage of these exciting opportunities and to meet the challenge posed by foreign competitors.

Over the last two decades, U.S. manufacturers have been complacent and product quality has suffered. This fact, coupled with the Japanese determination to be a commercial leader based on product quality, began the decline of U.S. dominance in world markets for manufactured goods. Today, U.S. managers are automating manufacturing plants and instituting managerial innovations to survive in international markets.

Knowledge of what other countries are doing to prepare for the 1990s and beyond is also cause for serious concern. While many countries appear to have well-defined goals for developing human resources to accomplish needed progress, U.S. industrialists tend to look more at hardware. As a result, U.S. technological superiority may be easily jeopardized simply by not educating enough qualified scientific and engineering professionals to research, design, and produce competitive technology. This paper addresses the need to improve

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the practice of manufacturing engineering and the quality of U.S. education for manufacturing, since both are important to the national response to changing technology and international competition.

THE MANUFACTURING ENGINEERS OF TODAY AND THE FUTURE

Manufacturing engineering is that specialty of professional engineering able to understand, apply, and control engineering procedures in manufacturing processes. A manufacturing engineer needs the ability to plan manufacturing practices; research and develop tools, processes, machines, and equipment; and integrate the facilities and systems for producing quality products with optimal expenditure. He or she must understand production, production control, design, facilities planning, plant layout, methods engineering, quality control, work standards, systems engineering, statistical process control, processing, and manufacturing engineering management—in other words, the whole spectrum of manufacturing concerns.

Based on an education that provides the ability to adapt to changing requirements, both organizational and technological, manufacturing engineers of the future must seek change and be willing to learn throughout their 35- to 45-year working life. Skills of the twenty-first century factory professional must include communication and problem solving, as well as scientific technological grounding and superior personal skills for team problem identification and resolution.

Although manufacturing is often regarded as a mature or even declining factor in our society, the profession of manufacturing engineering is an emerging discipline that is practiced in different forms, depending upon the manufacturing enterprise. As a result, it still differs from the established engineering disciplines, such as mechanical and electrical engineering, which are defined traditionally in terms of both educational degree and specific expertise. Manufacturing engineering is, in contrast, more defined by function and demands multidisciplinary capabilities in mechanical, materials, industrial, and systems engineering. As the basic concepts of technology, applications, and management merge, the discipline of manufacturing engineering becomes better defined.

In recent years, this emerging profession has been driven to change by two powerful forces: development of new technologies and a fiercely competitive international marketplace for manufacturers. In addition, practicing manufacturing engineers must increasingly grapple with rising manufacturing costs relative to manufacturing productivity as

well as societal constraints. These constraints include the supply of motivated manufacturing workers, the need to bring sociotechnical improvements into manufacturing, safety and health protection in the workplace and the product, and prevention of pollution during the manufacturing process.

Manufacturing engineers also need to think about and receive training for whole new areas of operation such as manufacturing in space. It is likely that high-value production requiring extreme accuracy and cleanliness can be profitably done in the microgravity vacuum of space in the foreseeable future. Medical manufacturing, also requiring extreme precision and reliability, is becoming a major industry. Medicine's replacement catalog alone has grown to include almost 1,300 natural and artificial spare parts. Collaboration among manufacturers, the health care sector, and academia in biomedical engineering probably has great potential.

Unfortunately, few educational institutions—whether they are colleges, universities, apprenticeships, or continuing education programs—provide the necessary curricula, lab facilities, or qualified faculty to educate students adequately in manufacturing engineering and technology. As a result, most major industries must invest significantly in educational facilities and personnel training to supplement the graduate's knowledge. Most industrial training programs require a minimum of two years to produce a quality manufacturing engineer because of the need for additional manufacturing-specific knowledge and skills.

In the future, major changes must be made in education and training to prepare those who will be responsible for the direction of manufacturing. Industry, academia, and government have important roles to play in this effort. Specific recommendations for change must be identified, and a cooperative effort to develop revitalized programs needs to be mounted as soon as possible.

THE CHANGING DEMANDS ON MANUFACTURING PERSONNEL

In the United States, manufacturing engineers and managers have traditionally come from the ranks of machine operators with significant on-the-job training and experience, but little or no advanced education. These individuals were successful in a labor-intensive manufacturing plant using conventional equipment, much of which is still in our factories. Without the computer, most technical support activities were manual and time-consuming, and most activities—such as setting standards; writing process routings; designing tools, gauges, and

fixtures; production scheduling; and plant layout—required many employees skilled in the basics of manufacturing.

In the past, university-educated engineers were frequently engaged in mundane tasks—routing changes, running prints, filing prints, and basic clerical tasks—allowing them little time for utilizing engineering abilities to implement innovative manufacturing concepts. Products were commonly designed by product engineers with little or no counsel from the manufacturing, quality, or technical support groups in the same firm.

As a result, many products were needlessly costly to produce and required special equipment to maintain tolerances and surface finishes that did not improve product performance. Communications were difficult in manufacturing plants with multisegregated functions, leading to extreme delays and losses. With little foreign competition and several layers of management in all phases of the manufacturing function, any problem could be resolved by throwing more money or more labor into that particular operation.

Competition in the world marketplace has accelerated the implementation of new technologies in American industry and forced changes in manufacturing operations and management (see Table 1). Products must now be designed both with careful consideration of cost and producibility and with the participation of the entire manufacturing organization. Under the heading of "concurrent engineering," manufacturing engineers work as a team to coordinate product design between the product engineer and the manufacturing support groups and to evaluate the feasibility and producibility of the product. Once the product has been reviewed and approved by each group, it is released to production. The team approach to solving manufacturing problems and planning manufacturing operations is widespread in industry today. To work well, team members must have well-developed interpersonal skills. The importance of these skills may increase with further integration of manufacturing operations.

A manufacturing team will include many different titles, job descriptions, and technical backgrounds, depending on the industry. However, three general personnel categories make up most manufacturing teams: production personnel, technical personnel, and managers. Production and technical personnel, designers, and managers are all required to understand the total system. Increased automation will affect manufacturing personnel at three levels of production: (1) the element level, which involves the process mechanization and the informational component, (2) the cell level, which is composed of a combination of automation elements, and (3) the plant level, which includes multiple

TABLE 1 Preparing for the Factory of the Future

Present Organization: Off-line Management	Future Organization: Real-time Management
Manual Outdated policies, systems, and procedures supplemented by informal organization	Computer-aided systems CAD, CAM, FMS, text processing, electronic mail, etc., supported by flexible policies, systems, and procedures
Divisive Overly divided into work tasks and between functions and layers	Integrative Integrating information network relying on some functional expertise, but in a more open and cooperative context
Disengaging Hierarchical approach which narrows and restricts effective problem solving, causing people to retreat into their own worlds	Interactive Interaction both internally and externally with vendor base and client system—internationally
Declarative Top-down commands with little listening or feedback	Interrogative Active use of "what if" scenarios, with heavy graphic support

NOTE: CAD—computer-aided design; CAM—computer-aided manufacturing; FMS—flexible manufacturing systems.

SOURCE: Reference 1.

cells. Computer-integrated manufacturing ties these levels together with common data bases.

Production Personnel

On the production floor, line personnel work at either parts making, parts assembly, or inspection and quality control. The assembly line has already been affected by automation, as demonstrated by the robotic assembly lines in U.S. auto companies.[2]

If not involved in assembly, most production personnel perform set-up and monitoring tasks for highly automated material-handling devices. These same people will, in turn, provide the support for automated machine tools in a cell or flexible manufacturing system and monitor for problems that cannot be resolved by automation. Such a change in duties means that greater technical skills will be required of the shop floor worker in the factory of the future, when retraining production personnel will be a critical factor for achieving successful factory operations. Retraining must include developing new thinking regarding the integrated work process and transforming the conven-

tional attitudes deeply embedded in the cultural fabric of both labor and management.

An area in which present skills will be relegated to off-line programming is inspection and quality control. The "inspector" will simply monitor the output from numerically controlled coordinate measuring machines or some other type of electronically controlled inspection device. For the most part, inspection of fabrication or assembly operations in the factory of the future will take place during the actual fabrication or assembly process.

Technical Personnel

Technical personnel carry much of the burden for making the factory of the future a reality. The technical category includes engineers and designers, data processors (e.g., programmers/analysts, data base administrators, and systems analysts), scientists, and manufacturing technologists.

Engineers from most engineering disciplines—especially industrial, mechanical, and electrical—become manufacturing engineers by participating in production operations. Industrial engineers, with their work in methods improvement, work standards, facilities design, systems analysis, and justification, are natural candidates. Mechanical engineers and electrical engineers also become involved in production processes, automated equipment, testing systems, capacity management systems, tool/fixture/gauge/machine design, graphics systems, and facilities planning.

In the future, a major role for technical personnel, especially data processors and engineers, will be building and maintaining "expert systems" and knowledge bases for artificial intelligence applications. Knowledge bases will consist of the processing logic and techniques necessary to perform functional activities such as detail design, process planning, numerically controlled machine programming, and facilities layout. Knowledge of how to perform each step in the production process, and of how to link these steps so that the planned product emerges, has always been necessary for production.

In the factory of today, this knowledge rests in large part in the minds of the workers. In the factory of the future, it will be the task of technical personnel to document this knowledge thoroughly in forms computers can manipulate and transfer to the common information system where anyone may use it. More specifically, they will:

- Document manufacturing and engineering processes for appropriate computer manipulation;

- Assemble necessary data on materials, vendors, products, and production processes (e.g., machining, composites, sheet metal, and assembly);
- Encode manufacturing know-how into expert systems;
- Conduct research to improve product/process technology; and
- Maintain, service, and monitor information systems.

Since technical personnel are primarily responsible for providing product definition and planning information, their roles become significantly more important as the information processing in a factory becomes more unified. Support and production personnel will work directly with information and through automated equipment systems supplied by the designers and engineers. The entire enterprise will be more integrated, allowing less opportunity for the discontinuity, confusion, and inefficiency so commonplace in today's factories.

In some firms, the computer already links designers and others in the organization. Designers of the future, however, will interact even more closely with other professionals in the organization. For example, designers of today view information on material and process costs, field service requirements, and some customer needs as largely advisory rather than constraining. As with catalog-type information, cost and process data must be developed and stored in a form a designer can retrieve and use if these data are to influence design just as strongly as form, fit, and function constrain it today. Current computer-aided group technology coding and classification systems used for process planning systems are inadequate for this purpose. Because the payoffs for guiding design concepts with early cost information are considerable, these systems will be improved and their outputs made available to designers.

To relate design better to producibility, the designer of the future must be thoroughly familiar with the firm's manufacturing processes. Designers must be prepared to perform stress, thermal, and vibration analyses, which were once the province of engineering analysts. Work methods will also change as computer-aided design systems become more nearly able to replicate the true geometric model of an object. Most current and near-term systems enhance the designer's ability to retrieve, communicate, and analyze information, but the decision making has remained with the designer. Expert systems will enhance this capability. As CAD/CAM (computer-aided design/computer-aided manufacturing) systems become more prevalent, the designer will carry out most analyses, reserving only exceptional tasks for engineers on the factory floor.

Managers

Managerial qualities for the factory of the future are essentially the same as those desired today: leadership, integrity, intelligence, foresight, flexibility, ability to make decisions, and an open mind. However, some attributes may become increasingly important:

- Capacity for strategic thinking and ability to react to major change—economic, political, or social—early enough to benefit the enterprise;
- Ability to cope with social forces that require changes not only in business strategy but also in management structure and style;
- Ability to cope with internal forces in managing human resources affected by changes in technology and employment; and
- Ability to understand government and regulations and capacity to influence government actions.

Despite the widespread cry that the economic vitality of the nation depends on restoring and upgrading its manufacturing expertise, U.S. factories are largely managed by those relatively unfamiliar with manufacturing. Senior corporate managers often have degrees in law or business and little grasp of new technologies or methods that can raise productivity and product quality. Even those who are engineering graduates are apt to have been taught little about manufacturing and, for example, problems of CAD/CAM systems.

Those who do understand manufacturing processes, tooling, materials handling, and systems—the manufacturing engineers—often learned their profession on the factory floor. Manufacturing engineers know how factories are run but, lacking sufficient education in either modern technologies or the business environment, they are ill-prepared for leadership in the factory of the future.

Tsurumi argues that too many U.S. managers are technologically illiterate.[3] In comparing the top three executives of 25 leading Japanese manufacturers with the top three executives of 20 leading U.S. competitors in such diverse fields as semiconductors, computers, consumer electronics, steel, autos, chemicals, pharmaceuticals, industrial equipment, and processed food, he found that two-thirds of the Japanese executives had science or engineering degrees compared with only one-third of the Americans. Furthermore, no Japanese executive without technical training rose through their legal or financial ranks, but over two-thirds of the American executives reached the top through careers as corporate lawyers, accountants, and financial officers. The

Japanese executives with nontechnical backgrounds had experience in domestic and international sales operations, while the American executives with nontechnical backgrounds had risen mostly through advertising and corporate planning. The latter is a typical career track for the new brand of American manager with a master's degree in business administration (MBA).

Preparation of U.S. executives allows them to remain aloof from the factory floor and the people expert in the day-to-day task of making products. If Americans entering leading business schools are technologically "illiterate," the current business school curriculum is likely to distance them farther from engineering and technology and perhaps even increase their disdain for hands-on experience. Once an MBA joins a typical company, opportunities for experience on the factory floor are limited and sometimes discouraged, with the result that many people managing U.S. companies are unfamiliar with crucial parts of the firm's operations. It is thus no surprise that U.S. corporations tend to be drawn to legal or financial solutions rather than technical ones.

Middle managers and supervisors make daily operating decisions. The factory of the future will continue to demand both practical technical and social skills on their part, in light of integrated communication networks; a larger cadre of knowledgeable workers and technical specialists; and increased artificial intelligence capabilities, office automation, common data bases, and decision support.

Some say that management is basically the same regardless of what is being managed, but this is not true of engineering management. The best-qualified engineering managers are those who combine both technical and management skills, since they must understand and apply engineering principles while they organize projects and direct people. They are uniquely qualified for managing either technical functions in any enterprise or broader functions (such as marketing or top management) in a high-technology enterprise. Unfortunately, many engineers do not realize what an important asset their engineering background is in pursuing a management career. Technical expertise is certainly not all there is to being a manager, but it is a primary requirement in manufacturing.

As U.S. industry begins to focus on strategies for developing personnel who can function as part of a manufacturing team, the skills and knowledge crucial for the unique circumstances of the manufacturing manager must be identified. These skills should, in part include experience in production, experience in sales, and understanding of the engineering and science base of the product.

SHAPING THE CAREERS OF MANUFACTURING PROFESSIONALS

To pursue a productive and enduring career in this era of revolutionary industrial change, the manufacturing engineer must be versatile and have knowledge of and experience in the many manufacturing operations. Industry can provide this exposure for recent graduates and other individuals through in-firm work experience programs which place each engineer in a series of diverse assignments over two or three years. Part of this career path plan should be related coursework in computer uses, new technology, maintenance services, and human resource management.

After working in manufacturing, however, highly qualified engineers often transfer into nonengineering or nonmanufacturing classifications that offer salary increases or other rewards. Manufacturers must recognize the loss they suffer when an experienced manufacturing engineer leaves the production function because there is no salary or promotion incentive to stay in that classification. Many times an individual would prefer to work in engineering, but he or she has found that moving up the promotional ladder requires a shift to a new type of work or a move into management.

The underlying concept of structuring a full career path provides a good example of an alternate way of creating a major resource of competent engineers and managers. Recently, a new professional classification, "advanced manufacturing engineers," has been implemented in large companies such as General Electric, General Motors, Ford, and Caterpillar. This classification encompasses major responsibilities in research, design, project management, and manufacturing management and can help retain and reward outstanding engineers who might otherwise move into sales, finance, or other service areas.

In many companies, the "manufacturing engineer" is replacing the separate classifications of industrial engineer, methods engineer, tool engineer, and process engineer. Interestingly, some of these same companies are asking for new curricula in the universities on manufacturing systems engineering to develop the skills needed to manage large integrated manufacturing systems.

These developments indicate that industry recognizes that the manufacturing engineer of the future will require work experience to understand manufacturing problems and a formal education in theoretical knowledge. The efforts under way focus on the critical issues in manufacturing operations today: quality, resource management, human resource management, the engineering-manufacturing interface,

managerial leadership, strategic planning, and computer-integrated manufacturing.

The use of better information systems can release the manufacturing engineer from more mundane activities and free valuable time for creative activities. They can provide powerful new tools for simulating new methods and concepts of manufacturing. More time and techniques will be available to develop research projects for product design and producibility. Then perhaps for the first time in a long while, manufacturing managers, even though they may be fewer, will have more time to devote to the human resource management and strategic planning so vital in the competitive marketplace.

Having the practicing engineers and trained technicians and technologists who share the core task in manufacturing engineering work closely together is in the best interest of the profession, industry, and our society. In working with the manufacturing engineer, the manufacturing technologist will be assigned to projects on design, development, and implementation of engineering plans; drafting and erecting manufacturing engineering equipment; estimating and inspection; maintaining manufacturing machinery or manufacturing services; assisting with research and development; sales and presentation; and servicing and testing of materials and components.

To perform these functions, the technologist must have sound knowledge of materials and manufacturing processes. Because formally educated technicians and technologists are certain to increase in numbers and in quality, it is better to ask what expertise is needed and then determine who can best provide that expertise.

It is important that manufacturing education at all levels incorporate the social and psychological interests of the individual and group as an integral part of learning. The status and condition of those who will work in manufacturing in the future are of great concern today. Foreign competitors have demonstrated that maintaining the good efforts of the entire manufacturing work force is indispensable to formulating and implementing strategy in the factory of the future. Manufacturing engineers must be aware of the new considerations that are part of the manufacturing revolution and must be prepared to handle the situations that arise. The factory must be reevaluated, recognizing it as a system of people and equipment with opportunities for a variety of interventions that will influence the people much more than equipment.

For example, a factory designer, factory manager, or (more rarely) a production worker can restructure work methods, rearrange tech-

nology, or redesign organizational social structures to improve the relationship between the social and human system of the organization and the technology used to manufacture products. When the systems are arranged well, the organization runs smoothly, output is high, employee needs are satisfied, and the organization remains adaptable to change.

Installation of computer-integrated manufacturing components, such as flexible manufacturing systems, robotics, transfer lines, and automatic materials-handling systems, provides a fresh opportunity to redesign the workplace to reflect both technical and human factors. Many industries are implementing improved sociotechnical systems today, particularly those moving away from conventional manufacturing methods into automated production.

Working relationships among organizational units so dramatically affect our ability to exploit the new technologies that manufacturing engineers must be prepared more effectively to deal with people, not just machines. Some estimates indicate that an engineer in industry spends a quarter or more of work time in the reporting process. As an engineer gains managerial responsibility, this proportion could increase to as much as 80 percent. Engineering schools must recognize this aspect of an engineer's career responsibilities and incorporate more educational experiences that develop interpersonal skills.

Attracting high-caliber engineering talent into manufacturing should be a priority for all involved. Industry must do its part by promoting changes within manufacturing that foster the desired attributes in individuals and organizations. The working atmosphere conveys, both directly and indirectly, the job situation. Sensitivity to change, appropriate job descriptions and personnel requirements, concern for human resource management, and specific career ladders all provide an atmosphere that attracts and holds those with the valued characteristics.

What salaries can new manufacturing engineers expect to earn and how are salaries affected by education and other factors? To answer these questions, the Society of Manufacturing Engineers (SME) sponsors a series of biannual salary surveys to track the salaries of manufacturing engineers and managers (see Table 2). As detailed by Langer,[5] the median annual cash compensation of full-time managerial personnel who participated in the 1984 survey was $42,960, while the median annual salary for engineers in manufacturing was $32,000. Ten percent of managerial personnel with 30 or more years of experience earned over $89,800, while at the other end of the spectrum, 10 percent of engineering personnel with fewer than 5 years experience earned

TABLE 2 Compensation in Manufacturing (Managers and Engineers), Median Total Income by Level of Education

Level of Education	Managers	Engineers
No college	$40,000	$30,000
Some college (no degree)	38,854	30,647
Engineering technician (two-year degree)	36,400	29,943
Bachelor's degree (nonengineering)	42,600	30,719
Bachelor's degree (engineering)	45,000	33,215
Graduate degree	50,000	36,000

SOURCE: Reference 4.

under $22,384. Level of education had a greater impact on the income of managers than it did on the income of engineers.

THE EXISTING EDUCATION AND TRAINING SYSTEM

Secondary Education

The quality of secondary education affects who is prepared to succeed in engineering education. In 1983, the National Commission on Excellence in Education reported a crisis in American education.[6] Among its pertinent findings were an overall decline in high school science achievement and a lack of adequate math preparation in secondary schools.

The fundamentals of technology should be a part of everyone's education, yet many of the nation's high schools do not offer the math and science courses necessary to qualify graduates for consideration by accredited engineering colleges. There also is a woeful scarcity of qualified teachers for these courses. In the United States, the average student receives one-third to one-fifth the hours of instruction in math and science as his or her counterpart in Western Europe or Japan. The Japanese commitment to technological development and to the necessary teaching of mathematics and science has contributed to their achievements.

The first International Project for the Evaluation of Educational Achievement, conducted in 1964, compared the abilities of students from 12 industrialized nations and found that the Japanese ranked first in mathematics.[7] It is probably these young people who are at the cutting edge of Japanese technology today. By 1970, Japanese youth in both the 10- and 14-year-old age groups scored first among 19

countries in a series of international science tests. The United States ranked fifteenth overall.

Little career guidance is available in most high schools and colleges on technology and engineering. Access to broader career information should enable young people to appreciate the importance and excitement of manufacturing and engineering and thus to choose appropriate high school and college programs.

Education and training in preparation for manufacturing can take many forms for the prospective employee. Some enter the field with no coursework and no degree, while others bring along nontechnical degrees. Some begin with technical/engineering degrees. As manufacturing becomes more technical, it will have a definite effect on job entry requirements and, therefore, on the educational programs needed in the United States.

Work Experience, On-the-Job Training, and Apprenticeships

Manufacturing engineering has been and still is an applications function. Approximately 70 percent of practicing manufacturing engineers in U.S. industry today achieved their position through work experience, coming up through the ranks without a formal college degree. These individuals usually began as machine operators on the production floor, moved first into machine set-up, and then to production line supervision. Many attended in-plant or evening courses within a company continuing education program to become qualified for positions in process engineering, industrial engineering (plant layout, methods, and work standards), and, in many cases, tool engineering.

Similar "hands-on" manufacturing engineers came from formal apprenticeship programs in tool and die making or machine repair, or were electricians and maintenance service personnel. These journeymen were taught basic mathematics, design, processing metallurgy, machinability of materials, and job planning while applying their skills in real manufacturing situations. Many earned college credits for this coursework and continued their education, receiving degrees in engineering or engineering technology.

The recent shortage of apprenticeship programs in the skilled trades has significantly reduced the flow of journeymen to manufacturing. This skilled personnel shortage is critical, as the factory of the future will require well-trained support personnel with an engineering back-

TABLE 3 Engineering Degrees Granted by American Colleges and Universities, 1973 and 1983

	1973	1983	Percentage of Change
Bachelor's degree (thousands)			
Electrical/electronic	11.8	18.6	+58
Mechanical	8.4	16.5	+96
Civil	7.7	10.5	+36
Chemical	3.6	7.5	+108
Industrial/manufacturing	2.9	3.8	+31
All other	9.0	15.6	+73
Total	43.4	72.5	+67
Master's degree (thousands)			
Electrical/electronic	4.2	4.6	+7
Mechanical	2.8	3.0	+7
Civil	2.2	3.3	+50
Chemical	1.0	1.5	+50
Industrial/manufacturing	1.8	1.4	−22
All other	5.2	5.9	+12
Total	17.2	19.7	+14
Doctorate or Engineer degree			
Electrical/electronic	820	623	−24
Mechanical	435	422	−3
Civil	411	436	+6
Chemical	405	388	−4
Industrial/manufacturing	147	118	−20
All other	1,369	1,267	−12
Total	3,587	3,259	−9

SOURCE: Reference 8.

ground to apply robots, sensors, diagnostics, and other sophisticated systems equipment.

College and University Education in Manufacturing

In 1983, American colleges and universities awarded more than 105,000 engineering degrees (see Table 3). This table, based on information gathered by the Engineering Manpower Commission of the American Association of Engineering Societies, also details the

growth in engineering degrees granted over the past decade and the relative change of population among the major engineering disciplines. Again, manufacturing engineering fares poorly at every level. This low representation is repeated in the population of practicing engineers. While there are roughly 1.4 million practicing engineers in the United States today, only about 2,850 graduate manufacturing engineers are primarily employed in discrete parts manufacturing.

Because manufacturing is an emerging discipline without a firm home in colleges and universities, little information is readily available on the academic preparation of manufacturing engineers. Table 4 shows the 1984 roster of programs in manufacturing engineering and engineering technology accredited by the Accreditation Board of Engineering and Technology (ABET). Additional schools are listed in the SME annual directory of U.S. manufacturing education programs.[9]

Engineering technologists and technicians follow a different curriculum from that of engineers, usually oriented toward applications and operations. While the technologist degree takes four years, the technician degree typically requires two years of college. Students in these programs cannot easily transfer to a regular engineering program.

Manufacturing engineers and managers working in an international marketplace may create new educational demands for foreign language training and introductions to foreign cultures. Educational institutions may need to provide more opportunities for such subjects in a manufacturing curriculum, both in the degree-granting and the continuing education programs.

Cooperative and Corporate Education

"Co-op programs," which combine education and work experience and integrate theory and application, are without a doubt, the best of all paths to a career in manufacturing engineering. This educational structure allows a student to work in an industrial position while earning credits toward a college degree. Although this concept has been a part of engineering education in the United States for many years, only recently have such programs taken on a new significance for manufacturing engineering education.

Co-op programs can benefit all concerned. In addition to enriching a student's educational preparation, a properly designed and administered program can be cost-effective for a company in terms of

TABLE 4 Accredited Programs in Manufacturing Engineering and Technology for Year Ending September 1984, Accreditation Board of Engineering and Technology (ABET)

Study Area	Accredited Programs
Engineering	
Manufacturing engineering	Master's degree
	University of Massachusetts (Amherst)
	Bachelor's degree
	Boston University (Boston, Mass.)
	Utah State University (Logan, option in mechanical engineering)
Engineering technology	
Manufacturing engineering technology	Bachelor's degree
	Arizona State University (Tempe)
	East Tennessee State University (Johnson City)
	Milwaukee School of Engineering (Milwaukee, Wis.)
	Murray State University (Murray, Ky.)
	New Jersey Institute of Technology (Newark)
	Oklahoma State University (Stillwater)
	Pittsburgh State University (Pittsburgh, Pa.)
	Rochester Institute of Technology (Rochester, N.Y.)
	University of Nebraska at Omaha[a]
	Weber State College (Ogden, Utah)
	Wichita State University (Wichita, Kans.)
Manufacturing processes	California Polytechnic State University (San Luis Obispo, Calif.)
Manufacturing technology	Bradley University (Peoria, Ill.) (mechanical design or operations option)
	Brigham Young University (Provo, Utah)
	Indiana-Purdue at Fort Wayne (option in mechanical engineering)
	Memphis State University (Memphis, Tenn.)
	University of Houston (Houston, Tex.)
Manufacturing engineering technology	Associate degree
	Central Piedmont Community College (Charlotte, N.C.)
	Forsyth Technical Institute (Winston-Salem, N.C.)
	Hartford State Technical College (Hartford, Conn.)
	Ricks College (Rexburg, Idaho)
	Thames Valley State Technical College (Norwich, Conn.)
	University of Nebraska at Omaha[a]
	Waterbury State Technical College (Waterbury, Conn.)

[a] Both associate and bachelor's degrees are ABET-accredited.

recruiting and hiring, training, additional work done, and release time for permanent employees. To be effective, a program must make the student's work experience an integral part of the firm's work schedule. Cooperative efforts over time have led to programs whose graduates have better academic and professional performance than their "non-co-op" peers. Companies such as IBM and Rockwell International have integrated their well-established co-op programs with their long-term goals to provide a potential work force familiar with corporate goals and philosophy.

Many large firms are implementing new cooperative work experience programs in which a few students and faculty members can utilize the firm's CAD/CAM systems for training and development projects. These firms have taken the initiative in opening their doors and becoming an active partner with the educational institutions. Detroit Diesel-Indianapolis, for example, has initiated a program which allows students and faculty to use selected equipment during slack time.

Implementation of additional cooperative work experience programs in manufacturing engineering will mean productivity earlier in manufacturing careers. This will, in the long run, help industry increase productivity and address the problems of applying new technologies.

Corporate colleges have been a part of formal education for many years, and are currently institutions of renewed interest.[10] During the boom years of the 1920s, the General Motors Institute (GMI) was started in response to the emergence of a new technology and a new product. GMI, which is now sponsored by several corporations, served as a model for many programs which followed World War II, when corporate education again responded to increased diversity and proliferation of new products.

Corporate and academic educational programs will, to some extent, compete for the potential student population in manufacturing. This will be particularly true for the high-technology fields, where industry should lead in the latest equipment and expertise. Similarly, schools and industry will recruit competitively for qualified manufacturing faculty.

Competition may also extend to external funding. Accredited corporate colleges are eligible for government funding, and in most cases, these institutions are becoming eligible for funding at a time when state legislatures are not sympathetic to new requests. This is particularly true in the northern industrial states where many corporate educational programs are located. Conversely, public and private colleges are approaching industry for endowment and other financial

support which it may prefer to retain for its own educational and research endeavors.

Competition may be mitigated by reexamining the mission of the university: not a "college education" per se, but lifelong learning. In that context, the colleges would be one part of an educational system, including corporations, community groups, professional associations, and libraries. Each organization would benefit from open lines of communication.

Continuing Education

Continuing education can take many forms. Because it is increasingly important for the manufacturing engineer to be involved in lifelong learning, several options in the form of cooperative programs involving industry, educational and professional organizations, and government need to be available at all levels of career development.

Although various forms of corporate educational institutions are growing, the stronger trend is probably toward a working relationship between existing colleges and universities and corporations. One good example of this cooperation is the program developed at Pfizer, Inc. and Marymount Manhattan College, which established a "satellite college" as a part of the corporation's training and development center. The program integrates the liberal arts and the specific job training needed by the company. As a result, a classroom-workplace bond is developed that allows both parties to achieve their continuing education goals. Other companies having similar programs include R. J. Reynolds Industries, Inc., and Tektronix, Inc., which also offer on-site higher education programs. The other types of corporate cooperative efforts with educational institutions may or may not include the granting of degrees.

Many colleges and universities are expanding their continuing education base, which includes working directly with industry in identifying needs and providing quality training. Most courses are flexible, being offered both on campuses and at corporate sites.

Although continuing education activities and cooperation have increased significantly, there is still a tremendous need for more than can be provided in the next several years. Even so, it is not at all clear that new educational institutions must be developed. Even in manufacturing education, the solution may be to enhance existing institutions. Academic and corporate colleges have, or can assemble,

the expertise to develop programs for new technology-related jobs. It is important to support the few existing manufacturing-related programs while refocusing manufacturing education on the needs of the future.

THE NATIONAL RESPONSE: WHAT IS HAPPENING AND WHAT IS NEEDED

Enhancing the quality of our manufacturing education system will require closer collaboration among manufacturing engineering and engineering technology educators, industry, professional organizations, and government. Toward this end, the Society of Manufacturing Engineers (SME) has been providing continuing education for engineers in the field since 1932. SME is now sponsoring 30 to 40 major conferences and expositions a year, attracting more than 250,000 attendees. It also sponsors annually more than 300 clinics, seminars, and workshops devoted to single subjects such as lasers, robotics, and machine vision. Finally, SME offers between 30 and 45 in-plant courses each year, and many of its publications are used in the classroom as textbooks and reference books.

At the present time, there are few places where college and university faculty can obtain concentrated upgrading in emerging technologies without committing extended periods of time and meeting the associated financial requirements. In early 1985, the Society of Manufacturing Engineers initiated a new continuing education program for those in the field of manufacturing. This new Center for Professional Development emphasizes manufacturing management and offers training in planning, organizing, and controlling manufacturing systems for automation and integration. Relevant courses for those involved in manufacturing education, taught by leading experts in the field of manufacturing, include classroom instruction with demonstrations, simulations, and hands-on experience with computer hardware and software. In addition, students can visit Detroit-area industrial installations.

SME also works closely with the colleges and universities in accreditation activities in which both academic and industry representatives visit campuses for evaluations. Over 125 student chapters on campuses throughout the country are sponsored by the local area senior chapters, providing an opportunity for students and engineers to meet.

The SME Manufacturing Engineering Certification Institute certifies two general levels of manufacturing personnel. For certification, a manufacturing technologist takes an exam after four years of experi-

ence, which can be formal education. A certified manufacturing engineer must have 10 years of experience and pass the exam. Both are required to be recertified every three years, which promotes continuous learning.

The SME Education Foundation has given over $2 million to colleges and universities during the last five years for equipment, scholarships, curriculum, faculty development, and research initiation. Through its Faculty Travel Fellowship Program, the TRW corporation provides funding through the foundation to defray travel expenses for faculty attending SME continuing education activities. In other cooperative efforts, a number of equipment manufacturers donate equipment, which is distributed through a foundation-administered proposal program to select recipients.

It is in the interest of industry to support graduate study and research in manufacturing, because industry benefits from the resulting increased productivity. Means of support might include, for example, funding for graduate study, stipends for company employees, fellowships, and funding for research through either individual corporations or consortia, with prior agreements to protect proprietary information. Industrial consulting and exchanges of faculty and industrial professionals are also a means of keeping educators apprised of practical industry problems and new technologies.

A recent innovation in industry-academia collaboration, developed in Great Britain, is the nationally funded "teaching company." This sometimes takes the form of a partnership between a manufacturing company and a university, in which young graduate engineers work in the company and are supervised jointly by a manager and a member of the engineering faculty. The graduate engineers work individually or in a team on a substantial engineering task agreed upon by the company and the university and aimed at improving the company's manufacturing methods and performance. Faculty become involved in management decisions and contribute to improving industrial practice, while the program educates manufacturing engineers of high quality.

The program helps some schools build their strengths in teaching fundamental engineering science while developing a stronger orientation toward engineering practice. Implementation of the teaching company program should be expanded in the United States.

In computerized manufacturing technology for a broad range of industries, the example provided by Japan is worthy of study and possibly of emulation. Japan has set up a national program in which work is distributed among universities for basic research in a multitude of small projects (average funding, $30,000 per project); government

laboratories for applied research in a variety of medium-sized projects (average funding, $300,000 per project); and industrial companies for development of a limited number of large projects jointly funded by government and industry (average funding, $3 million).

Background study, planning, and coordination are accomplished through committees that include members from industry, universities, and government. Organizational and administrative work is performed by appropriate trade associations and professional societies. Government and industry provide the necessary funding.

Another national program recently developed in Japan, "Methodology for Unmanned Manufacturing," will both study and construct automated and computer-optimized manufacturing plants. An early step in the program is development of a small prototype, scheduled for operation in 1985. The Ministry of International Trade and Industry has contributed $50 million to this effort, testifying to its seriousness.

In the United States, establishment of a system of institutes at selected schools with the best productivity-oriented manufacturing engineering capability could be an important vehicle for improving industry-academia collaboration and productivity in manufacturing. Funded by industry and government, a multidisciplinary staff would provide technical assistance to industry on manufacturing methods and productivity. Other nations developing similar cooperative programs are the Federal Republic of Germany, Norway, the German Democratic Republic, Czechoslovakia, and the Soviet Union.

Fortunately, in the United States there are signs of improvement in the atmosphere for collaboration. For example, the government has shown a willingness to reform the capital cost recovery accounting system (e.g., accelerated amortization of machine tools), to assist research and development cooperation between academia and industry, and to credit taxes for corporate contributions to U.S. university research. More tax incentives for industry/university cooperatives are needed, however, to provide adequate education for manufacturing professionals. Although schools can obtain assistance through hardware donations, industrial assistance in programs which develop people or course materials is much more difficult to obtain.

Several universities have launched collaborative programs with industry. In October 1981, Brigham Young University formed an "Alliance with Industry" to speed the development of new computer technology and to increase its rate of adoption by industry. More than 100 industrial representatives from 46 companies have met with the university faculty and administrators to discuss ways in which they could cooperate with Brigham Young in developing CAD/CAM ca-

pabilities and training personnel to meet industry's needs. Current membership in the alliance includes such leading manufacturing firms as Boeing, General Electric, Exxon, B. F. Goodrich, and GTE. Leading CAD/CAM and equipment supplier members include Applicon, Computervision, Calma, IBM, Hewlett-Packard, Tektronix, and Digital Equipment Corporation. Membership costs $10,000 per year, or an equivalent grant in equipment.

Alliance members benefit by gaining:

- A larger number of graduates with computer skills;
- Preferential treatment in recruiting employees through the university and increased corporate visibility among students;
- New applications software developed at Brigham Young at no cost;
- Assistance in training employees in new techniques;
- Close contact with a center of research on new methodologies and applications; and
- A ready source of consulting expertise and talent for solving technical problems.

Brigham Young benefits from:

- Students gaining experience using the latest computer and high-performance graphics equipment;
- Students using advanced software tools for class assignments and research projects;
- Faculty, in close association with industry, developing research projects on current industrial problems; and
- Faculty, with industry support, developing computer-related manufacturing curricula to better prepare students for industrial careers.

Among the more interesting collaborative initiatives coming from industry are those of IBM, Hewlett-Packard, and Control Data. In September 1982, IBM announced a $50 million grant program, in the form of both cash ($10 million) and equipment ($40 million), to help universities develop and update graduate curricula in manufacturing systems engineering (MSE). The program is designed to enable universities to teach up-to-date and cost-effective design and manufacturing concepts and techniques that require more attention in engineering curricula than they are receiving today.

Within two months, over 150 universities submitted preliminary proposals to IBM for MSE curricula, setting forth university qualifications, the proposed program, university resources available to support the program, commitment to a continuing MSE education

program, the university's ability to attract students, a timetable for implementation, and any constraints or dependencies for implementation. In addition to the 150 preliminary curriculum proposals, 112 separate proposals were submitted for CAD/CAM equipment, and 20 schools were eventually awarded a total of $40 million in CAD/CAM systems.

In mid-December 1982, IBM awarded planning grants to 46 universities to prepare final proposals for an MSE education curriculum grant. Following a comprehensive review, IBM awarded grants of approximately $2 million each to five universities for developing graduate programs: Lehigh University, Georgia Institute of Technology, Rensselaer Polytechnic Institute, Stanford University, and the University of Wisconsin-Madison.

Two other computer industry giants, the Hewlett-Packard Company (HP) and the Control Data Corporation (CDC), have also established innovative business-university partnerships. HP invested some $20 million in the college system during 1984, making it one of the top five U.S. corporate contributors to education. It supports education in traditional ways—by donating new electronic equipment and funding research grants, for example—but the company gives more than money; it also gives time. Its engineers teach full time in community colleges or universities for one school year. Loaned employees receive full salaries and benefits from HP, so there is often no cost to the school. In this way, students gain a valuable educational perspective, the school gains an additional faculty member and insights into the current needs of electronics employers, and HP increases its understanding of university capabilities.

CDC is developing a different type of program with a consortium of six universities. Dubbed the "Lower Division Engineering Curriculum" or LDEC, the program will be a computer-based curriculum for the first two years of an engineering degree. In particular, the educational language PLATO will be used to allow technicians to tie into the universities via LDEC for basic engineering courses. This program demonstrates CDC's commitment to providing accessible training and development opportunities for employees.

CONCLUSIONS AND RECOMMENDATIONS FOR ACTION

A major refocus is needed to revitalize this nation's manufacturing systems using cooperative educational efforts. Through some fledgling ventures and emerging cooperative programs between industry, education, professional societies, and government, the revitalization of

manufacturing engineering is already under way. However, these efforts must be expanded to reach full manufacturing potential and to allow the United States to compete strongly in the international marketplace for manufactured goods.

• Increased funding should be provided for studies in manufacturing engineering education to complement funding directed toward manufacturing research.

While manufacturing research is extremely important, education is the base upon which significant research and applications are built. This country's future will depend upon the preparedness of engineers to develop and manage highly technical and highly specialized manufacturing operations. As technology changes manufacturing, it should also change manufacturing education. Funding studies and experimental programs in manufacturing education could provide the direction and impetus for educational change.

• More schools should develop manufacturing options within existing engineering degree programs as well as start new manufacturing engineering programs.

Engineering faculty shortages, inadequate funding to begin new programs, and the traditional academic departmentalization of engineering disciplines should not prevent the implementation of new manufacturing programs. The "option" within an existing engineering discipline allows students to gain a specialty by taking a core of manufacturing courses drawn from several disciplines, while still obtaining the primary degree. In many cases, therefore, only a few new courses would need to be developed to implement new manufacturing engineering programs. Where feasible, these programs should be implemented as soon as possible.

• Industry needs to support more aggressively manufacturing education in colleges and universities.

For most industries it makes little sense to develop training programs that provide basic manufacturing preparation for their [illegible]. More direct support would allow colleges and universities to [illegible] to do what they do best: educate well-qualified engineers. While financial and equipment assistance is extremely important, joint efforts in curriculum development and faculty upgrading as well as cooperative education programs for students can also provide a more solid foundation for developing cooperative education-industry programs.

• The skills needed by manufacturing engineers, technologists, and technicians should be defined based on the factory of the future, not on the traditional academic degrees.

As disciplines merge and new skills are required, alertness is needed to ensure that personnel are not overutilized or underutilized in their jobs. A continuing analysis of changing roles in the workplace should serve to guide development of educational programs as well as provide reference definitions of job titles.

• The undergraduate preparation of engineers must be broadened to include topics in management, economics, and interpersonal skills.

In many cases, knowledge in these areas is weak or absent in engineering graduates. The inverse is true in schools of business and management, where training in technology is generally deficient.

• More tax incentive and other programs should be initiated by government for industry-university cooperation.

Government must continue to provide tax incentives that allow industry to contribute equipment and facilities to secondary schools and universities for their laboratories. The U.S. government should also examine programs, such as the Japanese basic research projects for educational institutions and industry and the "teaching company" concept in England, that could further enhance transfer of technology nationwide.

• Strategic planning is a must for the survival and growth of manufacturing engineering education. The basics of a specific strategy and policy must be formulated so that action plans can be documented and implemented.

Manufacturing engineering is a relatively new discipline in the United States. As in any emerging discipline, an extended period of time is required for a new philosophy and the accompanying practical ideas to be widely accepted. This period can be drastically compressed by good planning strategies and fostering of critical growth patterns.

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Meshing Education and Industrial Needs: Two Views

A View From Industry

EDWARD A. STEIGERWALD

WHAT IS THE PROBLEM?

The clearly declining competitiveness of the United States in the world marketplace has prompted increased concern about the health of U.S. manufacturing. Considerably shaken by foreign competition, the U.S. long-standing market dominance in manufactured goods is now threatened and, in some industries, lost. No longer is the future of American industrial development a clear extension of the past. In a great many cases, this problem derives from an earlier attitude of complacency, which resulted in a less than adequate job of evaluating and implementing new procedures and techniques that would enable U.S. industry to cope better with changing market conditions and competitive pressures.

Another basis of this problem is that insufficient resources have been devoted to the manufacturing function. Thus it has not progressed at the required rate and major changes are needed to create a manufacturing base able to compete successfully.

Several trends within both individual firms and industry sectors have contributed to the loss of manufacturing dominance:

- The shift away from manufacturing and industrial engineering as the driving function in manufacturing operations;
- A separation of production and manufacturing from other corporate functions, such as research and finance; and
- The decline of investment in manufacturing resources.

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The Shift Away From Manufacturing and Industrial Engineering

During the early fifties, there was a strong emphasis on the role of the manufacturing and industrial engineer in improving the efficiency and effectiveness of manufacturing operations. Companies encouraged these professionals to establish engineered material and labor standards, methods studies, attention to plant layout, routings, and scheduling. This concerted effort led to strong manufacturing operations.

Since then, however, the number of students studying the industrial engineering disciplines has declined. Simultaneously, engineering schools have shifted from an educational emphasis on the basic manufacturing industries toward the more glamorous applications of engineering that have not yet been fully applied to the manufacturing floor. Although there is a growing understanding of the importance of manufacturing as an engineering discipline, most students, counselors, and teachers are still deluged with statements dealing with the decline of the traditional manufacturing-oriented industries and a transformation into an information society.

Separation of Production and Manufacturing

The second trend has been a strong tendency to divide functionally and conquer. The engineering perspective has broken down manufacturing operations into small segments, which has tended to maximize the performance of each segment often at the expense of optimum integration of the whole manufacturing operation. This problem becomes even more severe when the interface of manufacturing with the other company functions is considered—for example, more effective coupling of both the manufacturing and market strategies into a cohesive competitive strategy.

Decline of Investments

The third trend has been a tendency to minimize financial investment in manufacturing resources. Classic accounting principles have stressed short-term cost reduction or short-term return on investment, resulting in an improper job of anticipating and managing the change process. Progress requires making investments in new equipment, new processes, and human resources.

Only recently has the importance of continued broad investment in manufacturing to take advantage of innovations been reemphasized (see Figure 1). Most processes involve an incubation period, followed by a steady, relatively rapid increase in the output parameter. At some

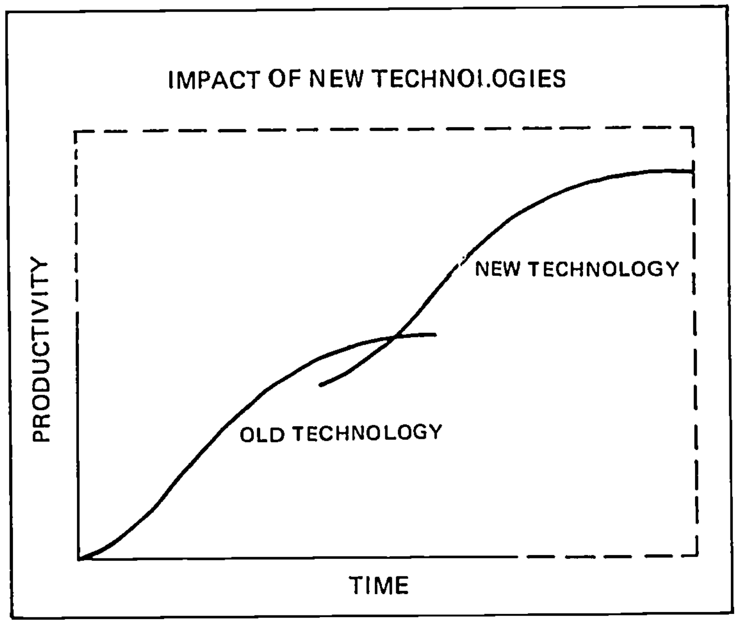

FIGURE 1 Characteristics of rapid productivity development.

point, the process reaches maturity and process productivity slows considerably. To maintain a steady, high rate of progress, continual moves must be made to new processes (a new technology curve) so that an average performance characteristic of the rapid growth portion occurs continuously. Indeed, outstanding manufacturing operations clearly operate and invest on this basis.

WHAT ARE THE NEEDS?

The needs for manufacturers and educators can be simply stated as attaining "excellence in manufacturing." Satisfaction of this need can take many forms and many paths, but it requires five elements:

1. Competent people
2. Elimination of waste
3. Functional integration
4. Implementation of advanced methods
5. A manufacturing strategy

The need for competent people may appear obvious, but neither manufacturers nor educators have done a good job of giving high

priority to attracting the best to the manufacturing discipline, or rewarding and retaining the outstanding people who are there. From a manufacturing management standpoint, the key way to obtain and retain good people is to provide clear, attractive career opportunities and interesting and personally rewarding tasks at every stage of career development. Excellence in any field of endeavor will be achieved by people who thoroughly enjoy and thrive on their work.

In industry, "career opportunities" are often interpreted as the opportunity to move out of manufacturing to administration and management, but this is a narrow view. Equally important are the opportunities for working within manufacturing to make strong contributions, to learn new skills and grow in maturity and judgment, and to be rewarded for this expertise. Employers must move to recognize and encourage the good work of those in the manufacturing function by applying the same key rewards that are so useful in other divisions of the company.

Both short- and long-term effects are needed to increase the number of competent people in manufacturing. On a short-term basis, outstanding qualified individuals must shift from product engineering or research and development (R&D) to manufacturing. On a longer term basis, a steady influx of properly trained graduates with new ideas and technologies should enter manufacturing and regard it as a challenging and rewarding career.

A comparison of the traditional and progressive characteristics of the work force is summarized in Table 1. Future manufacturing environments will depend on utilizing the entire work force to operate successfully, and manufacturing managers of the future must be able to tap this resource fully.

TABLE 1 A Comparison of Traditional and Progressive Characteristics of Work Force Management

Traditional Characteristics	Progressive Characteristics
Control	Learning
Management of effort	Management of alternatives
Coordination of information	Problem-solving information
First-order control	Second- and third-order control (Systems procedures vs. standards and norms)
Process stability	Process involvement
Worker-independent	Worker-dependent

SOURCE: From an address by Professor Steven C. Wheelwright, Stanford University Graduate School of Business, to a TRW Inc. manufacturing conference, Chicago, 1984.

The selection of competent hourly workers as well as managers must receive the necessary time and effort to support these future needs. Many current manufacturing operations select prospective workers after two to three interviews with fellow workers, supervisors, and the plant manager. At the TRW plant in Douglas, Georgia, for example, a selection/training process spends up to 80 hours on training and performing job tasks in a separate facility. A potential worker is evaluated in this work atmosphere prior to final job selection. This effort is worth it, considering that a new production employee earning $15,000 per year plus 30 percent in fringe benefits will cost the company more than $400,000 over 20 years. The time spent on selection of a $400,000 piece of equipment can serve as a comparison. People selection has been underemphasized compared to the effort expended on equipment selection.

The second requirement for achieving excellence in manufacturing is to eliminate waste: reduce scrap, control inventory closely, use human and capital resources effectively, and pay attention to the many small factors that contribute to an efficient operation. The best operations emphasize these principles and apply high-quality systems, "just-in-time" scheduling, manufacturing resource planning, personnel flexibility, and "flat" management structures. Manufacturing managers and technologists must learn how to make use of these emerging techniques and to develop them further. But how can this best be accomplished?

The third requirement for achieving manufacturing excellence is to integrate functions within manufacturing organizations. In each operation at TRW, a strong partnership is built of equals—R&D, design, manufacturing, marketing, sales, and all the supporting functions working as a closely knit team to execute the unit plan. Although each of these functions has different core responsibilities, there should be no isolation. It is not sufficient to get together just for the checkpoints—the design reviews and production release meetings. All functions must be continuous partners with a deep mutual interest in each other's success.

Dramatic changes can emerge, for example, from a strong, continuing partnership between design and manufacturing engineers—such as a change in a minor feature of the design, selection of an alternate process, or a better specification of tolerances. Suddenly the product is better, more readily manufactured, and far more reliable.

Implementation of advanced methods is another of the five discrete actions necessary to achieve excellence in manufacturing. Many manufacturing personnel are so overwhelmed by short-term production

pressures that they become isolated and lose sight of developments in the field. Perhaps the most urgently required initiative to improve manufacturing is the identification of obsolete facilities, equipment, and processing technologies, followed by the appropriate corrective action. Encouraging excellence, professionalism, and investment in both equipment and people must be kept constantly at the forefront to improve competitiveness.

Developing and applying a proper manufacturing strategy is the final item on the list of requirements to achieve excellence. Manufacturing units must have a clear vision and sense of purpose. Manufacturing managers need to think about and to participate more fully in developing production strategies that are totally consistent with the firm's business plan. What is the competitive strategy? What is the understanding of the manufacturing tasks? How do quality, delivery, price, and focus fit into these plans? Is the manager's perception of purpose and priorities consistent with those of the worker and first-line supervisor? These questions should be clearly answered to achieve the goal of manufacturing excellence.

FUTURE ACTION

Industry usually looks to the academic community as a resource that can contribute and develop:

- Educated people,
- Basic and applied research from which the products and manufacturing processes of tomorrow will evolve, and
- Expert, independent advice with specific knowledge not normally found in manufacturing operations.

These three activities are often combined. For example, the areas of expertise sought in potential faculty members are often dictated by the basic or applied research being funded. Outstanding students are then attracted to the disciplines taught by these capable, interesting faculty. Industry must therefore provide funding for manufacturing-related research and development to generate the interested faculty base.

The availability of faculty with the empathy and skills to motivate and to educate students to meet the requirements for a manufacturing career is limited. Thus attention must turn to developing faculty competence. Many remedies, ranging from increased funding for equipment to sabbatical leaves into industry to part-time teachers from industry, have been attempted. These are acceptable solutions provided

that they form part of an integrated solution that creates a strong manufacturing program rather than piecemeal or stop-gap measures. Since many of the changes occurring also involve the challenges facing major industrial organizations, the same condition applies to business faculty and business students.

Manufacturing will compete with many other disciplines for the attention of good technical students. In attracting competent people, industry must develop visible, well-paid, exciting career paths so that manufacturing is not a poor second cousin to corporate research and development, design, and marketing. Exposure early in a student's career, as an intern or a participant in a summer program, may effectively attract good people because manufacturing is exciting and often "gets into the blood." A properly designed assignment in the manufacturing function can get people "hooked" on the potential opportunities and contributions, leading them to decide to apply their talents there.

The working environment on the factory floor is changing dramatically with the advent of the computer and with renewed emphasis on productivity and quality as crucial factors of competitiveness. Use of the computer as a tool is becoming more pervasive in product design, machine control, production scheduling, and inventory control. Greater investments are being made in automation, robotics, continuous material handling, and flexible manufacturing, and this will continue and expand across American industry. A basic issue involves the actions needed to create an awareness of these rapid changes in technology. How can one develop the ability to utilize and cope with them, while still making a specific contribution in the manufacturing environment?

From an educational standpoint, a slight controversy exists between two overall options. Should the primary emphasis be on creating generalists with a broad knowledge of manufacturing or on developing a student with more detailed expertise in a particular manufacturing specialty? Although successful examples supporting either approach are available, knowledge of a specialty improves the acceptance of a beginner in the manufacturing function. The fact that a newcomer can contribute quickly in an area of expertise provides a useful base for developing confidence and integration into broader manufacturing needs. Industry often has difficulty placing "generalists" into the organization, the extreme case being the liberal arts graduate.

Whatever the proper mix in creating generalists versus specialists, one must not lose sight of the need for good engineering studies. Superior execution of the manufacturing process requires careful attention to the fundamentals that undergird new technologies and

organizational concepts. Building advanced manufacturing technology systems on top of poor engineering can never achieve the required results.

The proper curriculum for useful preparation in manufacturing is a key discussion item of this symposium. Recently, IBM launched a program to fund graduate curriculum development in manufacturing systems engineering. The many schools responding to the initiative defined core knowledge as elements of the proposed curriculum. These elements are:

- Manufacturing systems,
- Product and process design for manufacturing,
- New manufacturing and engineering technologies,
- Manufacturing processes and materials,
- Control of manufacturing processes,
- Production planning and control,
- Management of industrial systems,
- Modeling and simulation, and
- Business and economics.

In principle, these nine areas encompass the basic content of a manufacturing education. Execution of the program using the proper faculty, adequate facilities, participative teaching methods, workshops, exposure to real manufacturing problems, and the proper response by industry in defining career opportunities is absolutely essential to obtain sustainable results.

For the United States to retake its position as a world leader in manufacturing technology, industry and academia must jointly move the best people into manufacturing; provide adequate faculty, facilities, and curricula to educate them; and keep them. This is the challenge for the remainder of the 1980s.

A Response From Academia

ROBERT H. CANNON, JR.

What is the best way to get universities and industry on the same team to make headway on the national productivity problem? Mr.

Robert H. Cannon, Jr., is chairman, Stanford Institute for Manufacturing and Automation, Stanford University, Stanford, California.

Steigerwald aptly stated the problem: U.S. industries are suffering a declining ability to compete in the world marketplace as a result of falling productivity. This has happened, he added, because insufficient resources have been focused on the manufacturing function. He then developed the theme that the most important resource is the human one: top students have simply lost interest in manufacturing. He is right.

BUILDING EXCITEMENT

Addressing this point from the educator's perspective requires the first of five precepts presented here:

Precept 1: Students, faculty, and professionals will be attracted to university research and to careers where there is the excitement of newness and of doing something for the first time, where they can have mainstream leverage, and where there are resources to support them.

To excite students about manufacturing, one must first excite the faculty about the prospects in manufacturing. Top engineers will move into factories if this appears an exciting thing to do. Top professionals are the way they were when they were students: they want to move; they want to do new things.

Historically, one national focus after another has rallied resources and bright, motivated technical people to its cause in large numbers. These national crusades have included national defense (World War II and the "missile gap"), the journey to the moon, environmental protection, the energy crisis, and the productivity gap, and possibly include the computer gap, and the bioengineering gap.

Top students are not motivated to go into manufacturing careers by hearing, "Everybody who is going to be a manufacturing engineer, line up and take the following courses." A more effective method is to say, for instance, "Here are some exciting problems and some ways that new applications of basic physics can contribute to solving them."

For example, top-notch students are attracted to the Stanford laboratory in large numbers to work on robots unlike any seen before. These robots are flimsy, with very flexible manipulator elements—not the big, clumsy devices seen in factories today. Clearly, the next generation of robots will be light, graceful, precise, and intelligent and will know what they are doing and how to do it deftly. These characteristics will require not only applying but also *advancing* the basic theory of automatic control. Theoreticians send students to the

Stanford laboratory to find out what theories they should investigate to support the new applications. This challenge excites and attracts good students and academic researchers because it generates basic advances in a fundamental disciplinary area, which, of course, allow the advancement of applications as well.

Mr. Steigerwald also made a strong point about enterprise integration:

> The engineering perspective has broken down manufacturing operations into small segments, which has tended to maximize the performance of each segment, often at the expense of optimum integration. . . . Dramatic changes can emerge, for example, from a strong, continuing partnership between design and manufacturing engineers. . . . Suddenly the product is better, more readily manufactured, and far more reliable.

One must look at the whole enterprise and design, balance, tune, and operate it as a system. Reconfiguring the engine of production to take advantage of new and fast-changing technology is a research opportunity that generates excitement in a university atmosphere. It is also the kind of bait that will attract some top engineers, given that there are the resources to support them.

ATTRACTING STUDENTS

The remaining question is how best to use that bait to develop effective partnerships between universities and industry with the clear goal of getting good people and good new technical ideas into manufacturing. This requires three steps:

1. Attracting students to manufacturing-related courses of study and research and keeping them interested
2. Attracting graduates to the manufacturing arena
3. Attracting professionals to move to manufacturing as part of their career progression

Mr. Steigerwald addressed steps 2 and 3 in saying, "The key way to obtain and retain good people is to provide clear, attractive career opportunities . . . for working within manufacturing to make strong contributions, to learn new skills and grow in maturity and judgment, and to be rewarded for this expertise." He added that excellence is achieved by people who thoroughly enjoy and thrive on their work, and concluded that the number of competent people in manufacturing must be increased.

The shift, however, must go in both directions. A bright individual with substantial manufacturing experience can raise a lot of interest

and influence the direction of product R&D in very cogent ways. The way to move ideas is to move the people who have them. Could this kind of movement—for stronger motivation—be a prerequisite to promotion in some areas? Experience in design and manufacturing should be one central requirement for future leadership at higher levels.

In addressing step 1—attracting students into manufacturing-related studies—one must note Mr. Steigerwald's perceptive observation that outstanding students are attracted to the disciplines taught by faculty undertaking exciting research. Thus industry must provide funding for active manufacturing-related research and development to generate the interested faculty base. Professors are successful because they have good students, not the other way around. How does one generate the interested faculty base? In this regard, Mr. Steigerwald suggested some mechanisms, which are examined rather specifically from the university viewpoint in the following section.

BUILDING THE INDUSTRY-UNIVERSITY PARTNERSHIP

This section introduces two motivational issues related to research. The first will probably not appear immediately relevant to manufacturing, whereas the second will seem obvious.

Precept 2: Universities—people and teams—do what they are good at: advancing knowledge and teaching basic disciplines.

At first glance, this statement may make the game look hopeless. Nevertheless, engineers, even those in universities, like to work in a real world context, and this can ensure the movement of some university resources to manufacturing. This is, of course, related to Precept 1.

Some basic research areas relevant to manufacturing are:

- Computer science,
- Computer-aided mechanical design,
- Computer-aided very large systems integration (VLSI),
- Automatic control,
- Robotics,
- Behavior of materials,
- Expert systems,
- Chemical processes, and
- Operations research.

These currently exciting basic research areas relate to the five "manufacturing excellence" issues listed by Mr. Steigerwald. In academia, there are several dozen basic discipline areas that concern manufac-

turing. Thus this subject can be researched and taught without, for example, deciding to set up a new school of manufacturing.

The next issue is obvious:

Precept 3: Basic research—and therefore student and faculty interest and much of the teaching context—will focus on applications where there is fiscal support.

Money is a great facilitator, especially money to support students. Engineering schools are seeing larger numbers of excellent-quality applicants than ever before, but the competition among schools for these students is fierce. Students can therefore choose where they will go, and they will obtain fellowships. They will subsequently apprentice themselves to professors who have research support. If some of the fellowships and the research support are in manufacturing-related areas, these students will point their careers in that direction.

GETTING THE BEST RESULTS

What then are the mechanical details of industry-university interactions? The effective mechanisms were mentioned by Mr. Steigerwald: sponsorship agreements, summer jobs, internships, and, one could add, reverse internships—making it enjoyable and possible for industry personnel to spend substantial time on campus.

Precept 4 concerns interactions between industrial sponsors and university principal investigators (not university administrators). The initial connections are, of course, facilitated by the university administrative structure, and a number of universities now have manufacturing institutes just for this purpose.

The following precept addresses the companies directly:

Precept 4: The second most important thing companies obtain when sponsoring a university researcher is his or her insight into what new research might contribute to new opportunities for the company.

As bright students and faculty members become familiar with real manufacturing problems and opportunities, they will identify ways in which their research and teaching can contribute to the solution—new ways often not considered by those in the industrial community. The IBM grants program to encourage graduate-level engineering programs in manufacturing systems (see Brummett, in this volume) has very much operated from this precept, and it has expressed the tone and effectiveness desired by both sides.

Precept 5 concerns curricula:

Precept 5: Truly strong academic programs—strong curricula—derive from strong research programs; *not* the other way around.

Related to this precept is the idea of developing a Ph.D.-level *research* program that creates a new component for the M.S.-level management *teaching* program. For example, a Ph.D.-level research student could simulate a manufacturing enterprise on a computer. This kind of effort requires an individual who has been in manufacturing for a good while, who has hands-on experience, and who has come back to the university for an advanced degree—that is, someone who is quite knowledgeable about the cause and effect and the dynamics of what goes on in a factory. He or she might ask, for example, what effects will occur on the time constants of other things throughout the system if the inventory period is shortened?

The computer simulation would probably be simpler than real life in terms of number of products, number of machines, and so forth. It would contain, however, the cogent dynamic characteristics of the real enterprise, enabling one to learn something about what is important to the performance of the enterprise. This approach is similar to that used by engineers in simulating an aircraft to find its sensitivities. For example, a change in one aerodynamic coefficient makes no difference, but if another is changed, the aircraft becomes unstable. The second coefficient must be controlled carefully. The factory computer simulation research project could make the same kind of sensitivity analysis of manufacturing.

The important educational link in the proposed idea is that the simulation is made part of the M.S.-level program curriculum. Each master's-level student would operate the simulation to respond in real time, as a manager, to crises such as, "The widgets will not arrive on time, what should be done?" Or, "The paper broke on the printing press and you have a deadline to meet, what is the back-up position?" Students could then see how their actions reflect back through the system. This simulation appears to be a good training tool for aspiring managers of manufacturing enterprises, but the important point is: research serves as a beginning.

In this same vein, and to respond to Mr. Steigerwald's view about specialists or generalists, one does not want to educate specialists *or* generalists. The goal of a curriculum is to train people who have a deep grounding in fundamentals. This grounding can be learned in any number of contexts, one of which might as well be manufacturing. Pursuing a curriculum of basic technology in the manufacturing context

will work, whereas pursuing a curriculum of procedures and details will not work.

Finally, if an industry and a university wish to design a program in manufacturing productivity that will work to their mutual benefit, it must be custom-made. That is, it should build on the university's basic disciplinary and interdisciplinary strengths in computer science, materials formability, mechanical design, chemical processing, automatic control, expert systems, and so on. Such a program should be exciting to faculty and students alike. This requires that it contain a heavy component supporting basic research which will generate new directions for technology, and that it develop many mechanisms enabling faculty and students to become deeply acquainted with what is important to their industrial partner. These are the goals around which the mechanical details of structure, funding, interaction, and fair participation should be built.

Maintaining the Lifelong Effectiveness of Engineers in Manufacturing

ROBERT M. ANDERSON, JR.

For a long time, U.S. manufacturing enterprises had no major problems. Americans led the world in manufacturing experience for almost a century, and American manufactured goods dominated world markets. Today, however, manufacturers from other countries have adopted and improved new technologies (many of which originated in America) to become the high-quality, low-cost suppliers to world markets. American manufacturing organizations must therefore undergo a revolutionary change to incorporate a host of new technologies to regain or maintain their international competitiveness.

This paper begins by discussing the background and factors that relate to the problem of maintaining the lifelong effectiveness of engineers in manufacturing. It then presents a process for identifying what engineers need to do to keep up to date. This presentation is followed by a description of the drivers and the barriers to individual or organizational action as well as the mechanisms available to help an engineer maintain his or her effectiveness. Finally, the paper concludes with a call for leadership from those in industry, academia, and government.

WHAT IS THE PROBLEM?

Today's growing rate at which new technologies are being introduced into manufacturing has created a large demand for engineers competent

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in the new technologies. The universities, however, cannot produce new graduates in sufficient numbers or with adequate knowledge and skill to meet industry's need. American industry now faces the problem of breaking with tradition to maintain the lifelong effectiveness of engineers in manufacturing.

The Traditional Approach

Traditionally, maintaining the lifelong effectiveness of engineers has not been an important problem for anyone. A typical engineering career pattern entailed entering the profession at age 25, achieving peak technical competence at age 35, moving into a managerial or administrative position by age 40, and then somehow hanging on until retirement. New technology was developed in research laboratories, was taught in the universities, and was introduced into engineering practice by the newly graduated and newly hired. The whole system was reasonably stable; societal, industrial, professional, and individual needs were all being adequately met.

Although individual engineers following the typical career path may have bemoaned the compression of the salary distribution as a function of age or experience, they still got their salary increases year by year and they were still paid somewhat more than those with less experience. They grew comfortable and were reasonably confident of maintaining some position in their employing organization until retirement. Yes, they talked some about the need to keep up to date, but the pressures of the current work assignments together with the demands of family, community, and hobbies combined to keep most engineers from maintaining any serious program of continued study.

Managers of engineers saw no need to commit significant resources to maintain the latter's technical competence. The rate of introduction of new technology was such that new engineers with the necessary expertise could be hired, and sufficient managerial and administrative work existed (or could be created) to occupy the older engineers who lacked expertise in the new technology. Besides, managerial promotions resulted from solving real problems and from producing new products, new buildings, higher sales, lower costs, or higher quarterly earnings, not from maintaining competence of the emergency staff. If the technical competence of engineers in the group ever became inadequate to meet business objectives, the manager could always lay off those most out of date and hire a new batch of engineers with the required technical knowledge and skills.

Those in academic institutions also saw no need to be concerned about continuing education. They were fully occupied with the task

of preparing young persons for entry into the profession. Participation in continuing education activities was usually at the bottom of the list of things that "good" professors were expected to do. This list typically had research at the top along with publishing and obtaining grants, followed by teaching undergraduates and counseling, and ended with participation in continuing engineering education.

Government too tended to ignore the problem of maintaining the technical competence of the engineering work force. Except for the flurry of activity to place aerospace engineers as the space program wound down, government did little for the mid-career professional. Government scholarships, fellowships, loans, and loan guarantees were all aimed primarily at young persons preparing for entry into the profession.

In summary, maintaining the lifelong effectiveness of engineers in general, and in manufacturing in particular, has not been a high priority problem and no one has given it serious attention.

The Revolution of Today

A revolution in manufacturing is under way today. In a world much different than that 10 or 20 years ago, new technologies and new philosophical approaches—including parts per million quality standards, zero inventory, flexibility, automation, information systems, and communication systems—are being introduced at a significantly higher rate than in the past as American industry strives to be economically competitive in the world marketplace.

The traditional career path of the nondegreed manufacturing engineer who began as a production worker or craftsman and was promoted as a result of inherent skills does not and cannot provide the knowledge and skills required today. Moreover, current manufacturing engineers who have taken this path lack the fundamental knowledge and skills necessary to conceive and to implement modern manufacturing technologies.

Even degreed manufacturing engineers are ill-equipped to create and to install the new revolutionary technologies, which are not incremental extensions of older manufacturing technologies. Formal education in the physics of metal processing, for example, does not prepare a person to generate the computer software to control the metal processing equipment.

Thus, on the one hand, industry is being forced to introduce new and more complex technologies into manufacturing, while, on the

other hand, most of the existing manufacturing engineering work force lacks competence in the new technologies.

Can universities meet the needs in manufacturing engineering? The rate of introducing new technology into all segments of society is so great that the demand for engineers of all types is at an all-time high. Enrollments in engineering schools are also at new highs, and more new graduate engineers are entering the profession than ever before. Nevertheless, the demand from other sectors is so great that the number of engineers entering manufacturing is less than required.

Moreover, most engineering schools lack expertise in manufacturing. Their faculties are not competent in the modern manufacturing technologies, and they do not have courses or degree programs in the new technologies. Most universities are unable therefore to produce new graduates with knowledge of or skills in modern manufacturing technologies.

Based on this situation, ways must be found to achieve and to maintain the lifelong effectiveness of engineers in manufacturing. The old ways of hiring enough new graduates or promoting people from the shop floor cannot meet the need. Creative ideas, hard work, and commitment—not lip service—are required.

LIFELONG EFFECTIVENESS OF ENGINEERS

What Does "Effectiveness" Mean?

Is an engineer effective if he or she can write the software to download a numerical control program from a minicomputer to a programmable control on a machine? Is effectiveness knowing how to plan a flexible manufacturing cell, get managerial approval to proceed, and bring that cell into operation? What if an engineer has consummate technical skills, but is unable to communicate with persons up and down the management chain, to maintain a schedule, or to control costs on projects?

The concept of "effectiveness" involves knowing and being able to do many different things. Furthermore, the things that determine whether someone is effective will change as they advance in their career and as the technical requirements of their work change. Employee and employer share the responsibility for achieving and maintaining effectiveness in engineering. This is not a one-time task; it is a continuing process that merges professional development and technical education to keep up to date with new theories, processes, products, and industries.

How to Determine Effectiveness

Since the concept of maintaining effectiveness is complex, a straightforward process is proposed here for identifying and assessing the effectiveness of engineers in a manufacturing organization. The steps in this process are:

1. Draw an organizational diagram that shows every position in the organization held by a manufacturing engineer.
2. For each such position, list all the functions that the engineer must perform. For each function, describe its significance to the whole organization.
3. For each function, list the *present requirements*, that is, the body of knowledge and set of skills that the incumbent must have to perform that function.
4. For each engineer in the organization, list that person's *present state*, that is, the body of knowledge and the set of skills that he or she possesses.
5. Match each individual's present state against the present requirements of the position that he or she holds. Any present requirements which the engineer does not possess form the *present gaps*.

An incumbent who has no present gaps is completely effective in his or her present position. If some gaps exist, the individual's performance is less than completely effective. If the list of gaps is long and includes many significant items, the incumbent is ineffective.

Because the objective is lifelong effectiveness, one must also look into the future. This projection is crucial for manufacturing since the requisite skills for a manufacturing engineer are changing fundamentally and rapidly. It requires envisioning what the company will be like at some point in the future—for example, in three or five years—and what the engineering tasks in that situation will be. The process of determining effectiveness is then repeated as follows:

1. Draw an organizational diagram that shows every position in the future organization to be held by a manufacturing engineer.
2. For each such position, list the functions that the engineer in that position will have to perform. Again, for each function describe its significance to the organization.
3. For each function, list the *future requirements*, that is, the body of knowledge and set of skills required to perform that function.
4. Compare the requirements of the future position against the present state of the existing engineering work force. Try to identify

an individual within the work force who can now or with a reasonable amount of training and experience fill that position.

5. For each engineer who has been assigned to a future position, list that person's *future gaps*, that is, future requirements not met by the present state. (It might be useful to try a few different assignments to minimize the aggregated future gaps.)

Formulating the Development Objective

At this point, there are two lists for every engineer in the enterprise: one list of present gaps and one list of future gaps. For this process to maintain its own effectiveness, *written* lists must be compiled so that they can be discussed, debated, and refined. Careful judgment, both managerial and individual, must be exercised at this point to determine which gaps are significant, which will be addressed, and when. This process establishes for the individual engineer a *development objective*: specific knowledge or skill to be acquired and by what date.

Based on the above process, "lifelong effectiveness" for engineers can be defined as the process by which an engineer establishes a development objective and works to minimize significant professional gaps in both present and foreseeable future functions.

DRIVERS AND BARRIERS TO MAINTAINING EFFECTIVENESS

Once the development objective for an engineer is established, the engineer and his or her manager are about halfway toward achieving the goal of lifelong effectiveness. Considerable effort is still required, however, on the part of both the individual engineer and the organization. At this point, an objective has been defined, but to achieve it people have to do some things.

Why do people do, or not do, things? In "skunk" works projects, for example, a group wants to do something so much—or perhaps has such a strong sense of duty to do something—that in spite of a multitude of barriers, they accomplish the task. Alternatively, individuals or organizations sometimes fail to take action. Even though they have the ability and permission to take action, and even though it is clearly in their best interests, for reasons which may be difficult to articulate, they lack the will, desire, or commitment to achieve the goal. Why do people behave this way?

From an individual perspective, why does a person do a particular thing? He may do something because he wants to, because he should,

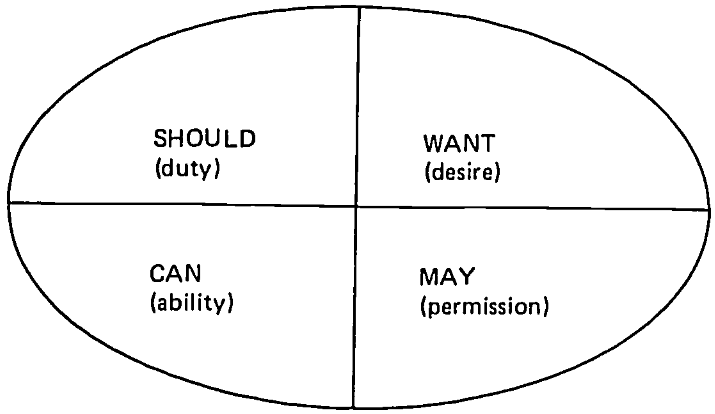

FIGURE 1 Drivers for action.

merely because he is able to, or finally, because he is permitted to. *He wants to, he should, he can, he may*: these four drivers for action can be represented as quadrants of a circle as shown in Figure 1.

Drivers for action should be examined from an organizational perspective as well. Motivating a manufacturing organization to maintain the effectiveness of engineers in the work force may require as much thought and preparation as specifying the individual development objective. The organization needs to understand the value and significance of this effort to its overall health, prosperity, survival, and market success. No amount of effort by lower-level staff can produce the benefits possible if upper management discourages this activity.

Why is it that a person will not do something? *He doesn't want to, he should not, he cannot, he may not*: these four barriers to action can also be represented as quadrants of a circle as shown in Figure 2.

Again, barriers to action must be examined from an organizational perspective. A firm may say it wants up-to-date manufacturing engineers, but it may send a different signal to the engineers. Meeting production schedules may be given higher priority than training, or worse yet, people who pursue training opportunities may be penalized by the organization.

The representations of a circle of drivers and a circle of barriers can be extremely useful. Overlaying the two circles is a convenient device, albeit crude and inexact, for increasing awareness of four factors to consider when one wants someone else to do a particular thing:

1. How much does he want to do it and why might he not want to do it?

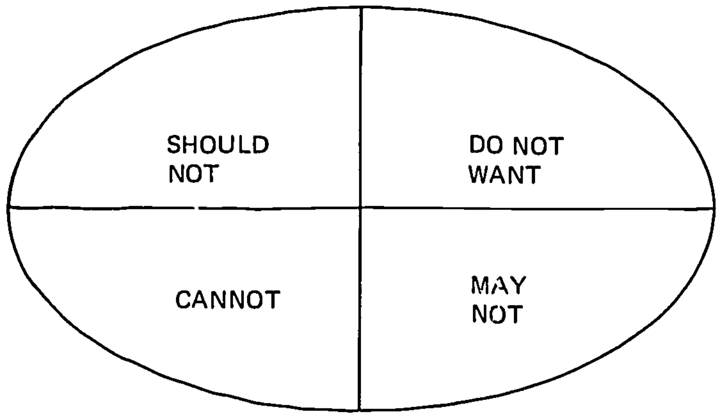

FIGURE 2 Barriers to action.

2. What is his sense of duty? Can we structure an obligation or is some other sense of duty acting as a barrier?
3. What is his ability and opportunity? Does he have the right position, access to the right information, or opportunity for the right training?
4. Does he have permission? Is some prohibition barring the action?

By weighing the net impact of these drivers and barriers, one can estimate probability of action. If one wants the action to be taken and if the probability for this appears low, then one must try to increase the appropriate drivers, decrease the inhibiting barriers, or both.

MECHANISMS FOR LIFELONG EFFECTIVENESS

After working to specify a development objective for an individual engineer and assessing the drivers and barriers to action, the individual engineer and his or her manager are still faced with choosing a specific set of actions to achieve the development objective. The actions or mechanisms by which people develop work-relevant knowledge and skills include job experience and education and training. Development is most effective when job tasks are structured to include growth opportunities and when appropriate education or training is used to enable or to support on-the-job growth tasks.

On-the-job task assignments are the most effective mechanisms for individual development. Tasks should be relevant to the business of the organization and significant from both a business and an individual development point of view. Learning from peers, subordinates, and

superiors can take place naturally and easily in the context of job performance.

Formal education and training are available in a wide variety of programs from a wide variety of suppliers. Short courses and seminars offered in-plant or at central locations by employers, professional societies, universities, and entrepreneurs are available on almost any topic. Degree programs and credit courses are available at local schools and are frequently brought onto the work site with live instruction or television.

Perhaps the most exciting new development in the delivery of education and training to employed engineers is the founding of the National Technological University (NTU). Formed in 1984, NTU will begin in the fall of 1985 to deliver master's-level engineering courses from a consortium of universities to engineers at their work sites by means of a television satellite distribution network (NTU originally delivered courses by videotape). General Electric, IBM, and Hewlett-Packard are but three of the companies that have pledged their support to help NTU get started and to provide the NTU courses to their employees.

The key to successful development is for the manager and engineer to agree on using those mechanisms most appropriate to the engineer's experience, ongoing work, and personal life. Both the engineer and the manager must treat this effort as a continuing responsibility and activity, not a one-time or a short-term effort. Development must become an integral part of doing business. The time and money needed must be made available consistently and reliably over several years.

CALL FOR LEADERSHIP

Engineering managers at every level of an organization must champion the cause of maintaining the lifelong effectiveness of their engineers. Jim Cudmore, vice-president of engineering for Digital Equipment Corporation (DEC), said in a speech at Northeastern University (September 10, 1984) that among DEC divisions he can see correlations of both business successes with strong programs of technical professional development and business failures with weak or nonexistent programs of technical professional development. The companies with excellent technical professional development programs, such as IBM and Hewlett-Packard, enjoy extraordinary business success in highly competitive and rapidly changing technologies.

The bottom-line payoff exists. If a business enterprise determines its investment action using traditional financial measurements such as

cost reductions and return on investment, then the case for investing in strong programs of technical human resource development has to be made in those measurement terms. Creativity is essential. One can calculate, for example, the financial impact on the business if a whole segment of the market is lost due to the failure of manufacturing personnel to stay current technologically. One can demonstrate that training and educating the present experienced engineers are less expensive actions than replacing the existing work force with new engineers. (*Costing Human Resources* by W. F. Cascio [Van Nostrand Reinhold, 1982] may be helpful in making these kinds of calculations.)

Active leadership is also needed within the academic community to support and defend those professors devoting significant time and energy to continuing engineering education. Because change in higher education institutions appears to have a certain glacial quality, as many of the existing academic programs must be utilized as possible. Technology must be applied to making course material as widely and as promptly available as possible, particularly in manufacturing where so few can teach and so many need to learn. A good example of this is the National Technological University's approach of televising on-campus graduate engineering classes for engineers at their work locations by means of satellite transmission.

Finally, leadership is needed from those in government. Public policies that inhibit the education and training of practicing engineers must be changed. These policies lay the groundwork for the mass obsolescence of American engineers and the loss of U.S. leadership worldwide in manufactured goods. Instead, more positive government incentives are needed to promote the continuing professional development of engineers in industry. Officials at all levels of government—national, state, and local—must provide the leadership to support education for professionals as an investment vital to ensuring the future of a free and economically successful American society.

Retraining the existing engineering work force to handle the new technologies and operating systems is the best way to make the most change in the shortest time. This is a big task and must involve manufacturers, educators, and the government. America's share of world manufacturing will be reduced if actions are not taken to provide American engineers the opportunity and the means to remain effective technical professionals for their lifetime.

Part 2.
Panel Discussion

Corporate Attitudes Toward Introducing the New Manufacturing Technology

From the engineering community, symposium organizers heard about persistent frustrations with the failure of firms to adopt beneficial new manufacturing technologies. The objects of these frustrations were frequently nontechnical considerations, such as senior managers unable to recognize the benefits of the new technology, financial analysis techniques such as return on investment (ROI), or hurdle rates that favor quick yield investments.

The ferocity of these expressions—and their sincerity—persuaded symposium organizers that both an obligation and an opportunity existed to air these subjects in a format that would enlighten participants on the cause and effect of these nontechnical considerations. In the spirit of the symposium, it was hoped to pass beyond the complaints to some constructive debate and, in particular, to examine how, if at all, education could improve the present situation.

Participants were asked to address:

- Corporate planning and changing manufacturing systems;
- Investment criteria and the introduction of new technologies;
- Management decisions and realization of the full potential of new manufacturing technologies; and
- How to develop the appropriate team of manufacturing professionals.

James F. Lardner, Jack N. Behrman, Michael J. Callahan, and Wickham Skinner participated in the panel discussion, which was moderated by Robert A. Frosch.

The panel discussion included four persons who have recent firsthand experience with the nontechnical aspects of changes considered in the technical/production operations of manufacturing firms.

Planning for Change in the Smokestack Industries

JAMES F. LARDNER

I am most familiar with the smokestack industries of the "rust bowl," which are among the most troubled American manufacturers. I will address primarily their problems of corporate planning for changing manufacturing systems. Significant problems are faced by these corporations when, in planning for the future, they must deal with major changes in manufacturing systems.

Based upon my experiences and observations, the continued pursuit of optimization of each of the specialized fractions of the manufacturing whole is producing an increasingly negative result. Reintegration of all elements of manufacturing should be the true goal of corporate management when creating new or renewing existing manufacturing systems. Accepting this as a goal, however, is an act of faith. In part, the reason is that establishment of a certain critical mass of new technology is required before the corporate bottom line is noticeably affected. Even the most enthusiastic chief executive officer must be concerned when he realizes the resource commitment and investment required to attain this critical mass. It is, however, absolutely essential to achieving results. We need to be more willing to accept this fact and to recognize the consequences of what happens if we do not.

When introducing new technologies, commonly accepted investment criteria are increasingly recognized as major obstacles. We currently operate in an environment in which discounted cash flows and internal rates of return are considered fundamental to evaluating investment decisions. In the industries with which I am familiar, the direct labor content in end products has been reduced to an almost insignificant amount as a result of years of concentration on making labor more productive.

James F. Lardner, vice-president for government products and component sales of John Deere and Company, has served in managerial positions for Deere and Company in Mexico and Brazil and as assistant general manager for two manufacturing works, manager of the plant and production engineering department, and director of manufacturing engineering.

Thus today, when looking for areas that can provide major increases in productivity, only two remain: (1) using fixed assets much more intensely than we have been able to do so far, and (2) controlling indirect labor costs—both blue and white collar. Although it may not be readily apparent, much of the activity of these workers involves structured decision making requiring little intellectual input and of a highly repetitive nature. Manufacturing information systems, computer technology, and programmable automation have demonstrated an ability to substitute for people in this activity, and it is important that management recognizes that most of the future savings will be here.

This opportunity to improve productivity and reduce overall manufacturing costs has been obscured by current cost accounting systems which do not deal adequately with "indirect costs." This suggests a real need to replace our present methods of analyzing manufacturing costs with new and better analytical systems.

There is an interesting difference in the way North American management and Japanese management approach the problem of increasing productivity. Apparently, something in our American culture demands theory to legitimize the action we take. This factor is particularly evident with design groups which have techniques for measuring what they are doing and then evaluating the results against a theoretical optimum. Unfortunately, no significant amount of research-based knowledge exists in manufacturing nor is there much of a theoretical basis for measuring the present results against optimum to evaluate alternative plans for change.

The Japanese use anecdotal observations and just plain pragmatism to determine how to move a product through a factory faster using fewer resources. If we operated like the Japanese, we would simply eliminate all of the wasteful practices that result from poorly designed and managed manufacturing systems. We need to understand, for example, that the "just-in-time" system is not an inventory reduction program but a manufacturing and quality improvement program. Thinking in broader concepts must invade every American board room and senior management group because there is not time to wait for research to justify actions that are needed to improve American manufacturing efficiency.

Identifying and developing a suitable team of manufacturing professionals to deal with problems in the factory may be an easier challenge than changing the perceptions of top management. Based on our experience at Deere and on my observations of other companies, the basic elements for much better manufacturing performance already exist. In my company, we have begun to use the long-discussed

techniques of matrix management and multidisciplinary project teams in design and manufacturing projects to solve problems on the shop floor and to address the challenge of just-in-time manufacturing.

New technologies require a new kind of organization and management. This demands acceptance of the principle that leadership of the project will be determined by the competence, knowledge, and skills essential to the project at each stage rather than management-designated authority. Although this principle is difficult to establish in the traditional management structures found in manufacturing organizations, it is fundamental to success. We have found so much good, solid understanding of manufacturing coming out of such projects that we may not have to wait for the results of some of the research we are presently trying to persuade universities to undertake. If universities hope to contribute to the ability of American industry to compete in global markets, they must direct their attention to research which deals with the basic elements of the manufacturing system and how they fit into the whole of manufacturing.

Engineers and the Application and Transfer of New Technologies Abroad

JACK N. BEHRMAN

I will describe a number of considerations that engineers, in particular plant managers and manufacturing officers, must have in mind when considering the application and transfer of new technologies. In doing this, I will emphasize the significance of foreign investment and foreign licensing by U.S. companies in the application of the new technologies.

Opportunities to apply an innovation in foreign manufacturing significantly increase the attractiveness of expenditures for research and development. These opportunities arise in the ability to invest abroad in manufacturing to serve either the home, host, or third-country markets (or a combination of these), or in the ability to license new technology to foreign companies for their use and sale abroad. Any of these routes increases the return on investment from application of new technology and thereby enhances the probability of a positive corporate attitude toward introducing new manufacturing techniques.

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However, these same opportunities may be served with a lag—that is, really *new* technologies are introduced first in the home market, where they are tested and modified for worldwide market application. In the meantime, the existence of foreign opportunities means that present (and recent) technologies can be moved offshore, where they can continue to serve relevant markets profitably.

TRANSFER OF MANUFACTURING TECHNOLOGY ABROAD

The attitudes of U.S. corporate managers to transfers of manufacturing technology abroad depend on four major factors: (1) their own corporate orientation to such transfers, that is, what they are willing to transfer overseas; (2) the kind of industry they are in; (3) the markets that they anticipate serving; and, (4) the policies of host and home government. All these factors are influenced by the economic effects that the technology and its transfer will have on a number of other factors.

The primary long-term effect of international transfer of new technology is that it shifts the location of industrial activity. This has important political and economic impacts both abroad and in the United States. A relocation in the site of production shifts many of the benefits of production and trade as well. Even if the production location is not shifted within a foreign country or among foreign countries, product lines may shift.

We are now finding that the new manufacturing technology demands a product design that allows parts to be produced in different locations around the world. We are facing therefore a new economic effect from the technology: changing linkages among subsidiaries across national boundaries that alter the degree of integration or separation of production activities.

The initial transfer of technology has several secondary impacts. It shifts the capital equipment used, the site of producing the capital equipment, and the investment required. In turn, these decisions determine the labor skills required to apply the technology; the employment resulting from the technology; the trade patterns that will result, not only in terms of the trade of components, but also of the final product; and, finally, the willingness of the host country to permit that technology to flow in continually from outside, as distinct from attempting to generate it internally. These broad effects, which must be taken into account, will alter the way in which the technology is transferred, or what technology is transferred.

Specific decision criteria for a company looking at technology abroad begin with the market to be served. If it is the domestic market in the host country, say Mexico or Brazil, the company will then transfer the technology appropriate to the consumption or industrial needs in that country. If the host country is to be used as a base for sales in a regional market, say Southeast Asia or Latin America, then the market demands in the region and the level of the market in terms of sophistication or growth are of concern. If a particular location is to serve the international market, as out of Singapore or Taiwan, that market, which is generally at the highest level of technological demand, then determines the kind of technology going into the host country.

Now the company must face the question of political and economic uncertainty in the host country—the greater the uncertainty, the less likely a corporation will transfer high or new technology. The corporation does not want to lose the technology, nor does it want to prepare would-be competitors. High-technology transfers therefore motivate the corporation to control the transfer of technology to the foreign subsidiary through either investment, a precise licensing contract, or a tight contractual relationship.

In response to relatively low levels of control or certainty in the host country, corporations increase their so-called "mobile activities" investment—that is, the ability to pick up the operation and move it somewhere else fairly quickly and at low cost. If little control and certainty exists in the host country, corporations seek ways to reduce the impact of losing even what control there is. One way to increase certainty is to link the activities in any one country with activities in another. In this way, if production in country A is taken over by the government, it is not particularly valuable to the government.

Product lines with rapidly changing technology are largely capital goods, industrial goods, or more sophisticated goods. Thus high technology is primarily introduced in and moved among the advanced countries. The developing countries are trying to pull high technology into their orbit. Brazil, for example, is going to buy or develop its own technology and produce and sell its own electronics. It is literally restricting the number of customers who can be served by foreign affiliates. No matter how much technology relative to informatics has been transferred into a Brazilian subsidiary, it will simply not be used to serve the local market. The Brazilians are not satisfied with merely obtaining mass consumption goods, or low-technology goods, even if they could sell them worldwide. They are concerned about the prospects of remaining backward or technologically dependent. Even if a U.S. company transfers technology and helps the Brazilians adopt

it, it still stands to lose the investment through the kinds of creeping controls Brazil has imposed.

Another factor affecting a company's decision to go overseas with technology and what technology to transfer is the absorptive capacity of the host company or country, if a new company is being set up. Absorptive capacity includes the user's ability to know: (1) what technology he needs, (2) how to get it, and (3) how to retain manufacturing engineers able to operate it and to instruct labor. In some studies we have made of technology transfers, the ability of the user to identify and to learn how to absorb the technology has been the critical fault, not the ignorance of the licensor or the investor in how to construct or to transfer the technology.

From the standpoint of corporate strategy, no company prefers to manufacture abroad. All prefer to produce at home, where the culture, economy, politics, work habits, and management orientations are known and presumed more "predictable." From this solid base, companies can then serve foreign markets through exports. It is also preferable to develop the technology at home, in-house, but since it cannot all be done this way, some is imported as needed and some exported as demanded. These exchanges are minimal or lead to interlocking arrangements (cross-licensing and patent pools), as was the case in the 1910s, 1920s, and 1930s.

The closing of markets in the 1930s, which continued after World War II, led companies to consider offshore manufacturing or licensing for manufacture abroad. The major trade-off is the loss of control, however, and companies prefer 100 percent ownership through investment. Licensing of technology can result from the desire not to expose the company to substantial capital risk through foreign investment, the small size of the market abroad, or the host governments' insistence on licensing as compared to investment (as in Japan in the 1950s and 1960s). Licensing can also occur when the licensee has complementary technology wanted by the licensor, or when the licensee is to become a supplier of intermediate materials or components at a lower cost than available to the licensor at home

The decision as to the mode of overseas ties is seldom made on the basis of technology alone. The kind of technology transferred tends to be dictated by the market size and sophistication, its growth and change, the ability of the affiliate or licensee to utilize the technology, and the capacity (scale of) production. The ability of the foreign labor force to apply given technologies is a critical limiting factor, and the company's ability to reshape, unbundle, or modify the technology so that it can be applied by less skilled workers has been a strong

contributing factor in the move of many companies overseas—especially into low-wage countries. Many companies have developed technologies and designed products so that processes and components can be rebundled and produced in diverse locations and then brought together in several places for assembly.

Technologies have not been a significant factor in decisions to invest overseas in advanced countries, for U.S. companies have simply applied the technology appropriate to the foreign market. New technologies give the developer a differential advantage in foreign markets, but the existence of such technologies does not drive the foreign investment decision. It does, however, sometimes drive the host government's willingness to accept such foreign investment (when it would prefer that the investment be made by local companies).

Application of a given technology abroad opens opportunities for still newer technologies, whether from within or outside the company. This happens because new markets are opened to the company, expanding its ability to shift production and processes. Its total scale is larger. Further, if the application abroad is through a licensee, the company can develop or adopt new technologies quite readily, since it will continue to receive royalties on the older technology as long as it is used by the licensee. The company is not, itself, locked into the older technology. Even where the investment is direct (its own), and the operation abroad is for production of a component (e.g., semiconductors), the company's capital is so small compared to the value of production that any shift in technology can be adopted abroad if workers are trainable, or the production can be moved back home if the new technology requires higher-level skills.

Only when the technology requires huge capital expenditures for equipment in place (e.g., petroleum refining) does the application of technology abroad tend to lock in the mode and scale of production as well as its location. Even here, new arrangements for contracting versus direct investment have increased the flexibility of such U.S. companies around the world.

EDUCATION OF MANUFACTURING ENGINEERS

Engineers need to be aware not only of how economics and politics affect the transfer of technology abroad but also how technology selection and transfer affect corporate structure, organization, ownership, location of production, integration, flexibility, and other factors. For example, the company transferring high technology very likely

wants to control the technology. It will therefore organize activities between itself and the host country, or the subsidiary and the parent company, in such a way that it keeps control—not only organizationally and financially, but marketwide and technically in terms of ties with the R&D center. In other words, the company simply fans out from the center and maintains a high degree of integration.

Low technology is treated in a less controlled fashion and, in fact, may even be divorced completely from the center. If the foreign country becomes interested in having that technology itself and nationalizes the subsidiary, the loss is then small.

The parent company therefore regards ownership as very important with high technology and less important with low technology. Integration of the company's activities is much more important with high technology than with low technology. Thus the type of technology transferred affects the organization and operation of the business. Even the nature of the industry matters. For example, the chemical industry is now much more ready to license technology overseas. Because a very large investment is required to go into petrochemicals and because the sector is controlled by governments—even the market is controlled—licensing becomes an appropriate means of transferring technology. The chemical companies are willing to do this, but in electronics the desire is for investment, ownership, and control—not licensing.

Technology transfer also has a number of impacts on business which the manufacturing engineer should know and which should be built into the education. Thus the prerequisite is to complement engineering and technology skills with an awareness of social, political, and economic effects. Engineers will then understand management's problems in looking not only at the market for the product, but also at the organization and control of the company itself.

Harvard Business Review recently published an article on business schools and what their jobs are. The association of business schools is working on how these schools can be part of the solution of the manufacturing problems question. We are, no doubt, a part of the problem at present with regard to some of what we teach on methods of cost control, accounting, and setting financial objectives.

Some companies have created a block to diffusion of technology within the company because of the financial targets they have handed individual managers around the world. None of these managers is about to transfer the latest developments in technology which they made in Belgium, even over to Germany, because each is a profit center and the Belgians do not want the German profit center to beat

them. This attitude toward motivating managers comes from business schools.

What I was suggesting earlier is not that manufacturing engineers go through the business school courses, but that they understand that business must face political and governmental issues. Similarly, economic impacts, the impacts of technology on company integration, and the resulting constraints on the transfer of technology must be heeded as well. Manufacturing engineers must understand all these effects and contribute to the solution by demonstrating that competition is not going to be on the profit line, but on the quality and cost line.

Competition around the world these days is based on cost reduction, not profit maximization. Business schools must recognize this situation, but this argument must be made repeatedly by the manufacturing community. This community must show how to raise quality and cut costs by adopting new procedures. This will help the bottom line, but that is not the purpose of the company—its purpose is to remain competitive and survive. Engineers need to recognize and understand these issues, but I do not suggest sending all engineers to business school.

Manufacturing Issues in the Semiconductor Industry

MICHAEL J. CALLAHAN

As probably the only participant from a semiconductor manufacturing organization, I will briefly describe our industry and some problems we face in manufacturing which are not much different than those of almost any industry.

According to the forecasts, the semiconductor industry will more than double its sales volume by the end of this decade. It has been and will continue to be in a state of continual technological change and subject to high competitive pressures. In 1983, for example, there were 35 worldwide manufacturers of semiconductors, each having net sales greater than $100 million and not one having greater than 20 percent of the market. In Silicon Valley, a new semiconductor company seems to appear every month. Many of them make it; many do not.

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This rapid growth, coupled with technological change stimulated primarily by competition, has required enormous capital investments on a continual basis. Over the last five years, for instance, semiconductor manufacturers have annually invested over 15 percent of sales in capital expenditures. In the next five years, this number will probably increase to more than 20 percent of sales. While a significant portion of this investment is certainly for capacity expansion, we are continually upgrading existing manufacturing areas. Any manufacturing line in our business will probably have either replaced or upgraded 90 percent of its total equipment within a five-year period. These upgrades are usually stimulated by improved processes rather than the desire for increases in raw productivity.

The technology changes made, however, have continually increased productivity in the industry. Over the last 10 years, the sales per employee of the semiconductor manufacturers in this country have more than doubled, and we have tripled the value added per employee over the same period of time. Thus significant improvements in productivity were achieved—not driven primarily by raw productivity issues, but by technology change and improvement. Industry management, who in most companies have an engineering background, not only accept change in the process and manufacturing systems, they encourage it.

U.S. semiconductor manufacturers face very strong competition from companies in Japan. Success in this competition will depend on continued capital investments and development of innovative products and processes: however, this will not be enough. We must further address the manufacturing processes themselves, placing greater emphasis on production issues rather than just on technological change. We must significantly shorten cycle times in manufacturing processes, handle small lots of material efficiently, and develop "just-in-time" delivery systems for ourselves and, most important, for our customers.

A short-cycle time for any manufacturing process significantly increases the learning rate of the engineering community working on the manufacturing process and thus drives programs in production cost reduction. Cycle time reduction is critical to our gaining the competitive edge for cost and price leadership. Furthermore, the increased capabilities resulting from process innovations and improvements in manufacturing equipment have put us in a position where we must customize products for the end-user. Devices are becoming so complex that we are putting major portions of their systems onto one piece of silicon. Thus the personality differences between our customers' products reside in the components we build, with the result

that the numbers required of any particular part type of these complex devices may be relatively low by today's standards.

This is a complete departure from what we have historically regarded as economies of scale. However, we must learn how to process small lots quickly and economically at high-quality standards if we are to remain competitive in the future.

Today, our customers are trying to lower their inventories and develop low cycle times in their own factories. To be competitive worldwide, we must generate the capital needed to improve equipment, not inventories. The Japanese invest higher levels of sales in new plants and equipment significantly more than we do as a whole. Our customers want their vendors to deliver products "just-in-time." We could hold inventory for them, but for obvious reasons this is not an acceptable solution. Better forecasting will help, but in my view, streamlined, short-cycle-time manufacturing systems are the answer.

Modeling a manufacturing system on a computer terminal while sitting in an office is not the way to do it. Systems can only be designed by people who understand the technologies and equipment they are dealing with, and these individuals are manufacturing engineers. However, these same manufacturing engineers, who come from all disciplines, must be taught additional skills and be capable of functioning in a manufacturing rather than a laboratory environment. In semiconductor manufacturing, engineers need exposure to that part of the manufacturing discipline dealing with flow optimization.

Why is this taught in the business school anyway? Manufacturing engineers must be taught how to model and optimize flows, how to manage inventory, and most important, how to manage people. Direct labor operators are an enormous source of problem-solving information and often have many years of experience. Probably very few of the top engineers in my company, or in many companies, have ever taken a single course in any of these subjects, so we must try to broaden the training for our engineering students to touch on these and other subjects.

Just as important, they must view manufacturing as a professionally and economically rewarding discipline. Good examples of this are our industry's manufacturing engineers, many of whom have advanced degrees and work on the manufacturing floor, developing and improving processes. A good indication of the esteem in which they hold manufacturing engineering, even though they do it 90 percent of their lives, is that they are called process engineers, not manufacturing engineers. If they were called manufacturing engineers, we would have a hard time recruiting half of them into that profession. We will only

accomplish what we have to in this area when industrial management and university educators indicate that they regard the manufacturing discipline and profession as highly as the professions of research and development and design.

Challenges to be Met

WICKHAM SKINNER

My overall conclusion, after three years of research on the introduction of new manufacturing technology in about a dozen firms, is that progress is very modest. When one considers the urgent requirements for restoring our competitive edge and improving industrial productivity, it is quite surprising that industry has not moved more quickly to take hold of up-and-going technologies.

Essentially, there are four reasons why progress is so slow. First, a lengthy period of tinkering and adjusting is usually required to start up the equipment, get the bugs out, and handle the interfaces with other, conventional processes. Second, the vendors serving industry are very disaggregated. Few turnkey contractors or operators or producers will put the whole equipment or technology together. Third, decisions to introduce technology are adversely influenced by our financial and accounting colleagues. The introduction of new manufacturing technology typically must be justified on the basis of paybacks and discounted cash flow. The hurdle rates are high, particularly a few years ago when interest rates were so very high. New technologies change the cost mix and subsequently may alter the financial structure of the business, but the extraordinary fact is that major investments in new manufacturing technology can seldom be justified by cost savings and paybacks. Their powerful advantages arise from their significantly improving the company's strategic ability to compete.

Fourth, in observing how manufacturing management decisions are made, there is a clear need for champions to introduce changes, bring them to the attention of top management, and come back with the money. Many smart manufacturing managers will hesitate to champion an appropriation at high levels, for it will inevitably mean a big

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investment for the company, usually a risky one, and such investments may not only mean betting a division or a plant but also a career. Managers know that once they undertake these efforts, three or four years of trouble and hardship are needed to make them work better than the status quo. The result is a very conservative approach on the part of manufacturing managers.

In looking back at the major changes in industrial history, the gradual development of textile machinery took 30 or 40 years, as did mass production powered by coal and oil in the process industries. The so-called "American system of manufactures," studied very ably by Johns Hopkins professor David Hounshell (*From the American System to Mass Production 1800-1932*, Johns Hopkins, Baltimore, 1985) took 40 years to incorporate interchangeable parts, in spite of the benefits to the manufacturer. A study by David F. Noble (*Forces of Production: A Social History of Industrial Automation*, Knopf, New York, 1984) shows that 40 years were required for the use of numerically controlled machine tools to become well established. Thus from a historical perspective, it has always taken a long time to diffuse technological change.

But can we say, "Well, that's history. That's the way it'll be." Of course, we must not. The new manufacturing technology represents too great a hope for regaining our productive and our competitive edge. What then can be done to improve the current disappointing rate of progress?

The present industrial scene is one of considerable pressure and dissatisfaction. In 30 years, I have never seen more frustration between top managers and manufacturing managers, as well as more frenetic activity toward working our way out of our current industrial dilemma. At top corporate levels, senior executives urgently demand changes, improvements, and ideas, as well as lower production costs and better quality from the manufacturing function. But at the factory level, manufacturing managers complain that they must meet short-term monthly and quarterly goals and that they are held accountable to "archaic" accounting systems, the same systems that have focused for 100 years on minimizing direct labor. And in spite of pressure from all sides, production managers are skeptical of high-priced, fancy machines and computerized systems equipment. They see these innovations as risky, and they would rather experiment on a small scale than make massive changes.

The hang-up stems from corporate attitudes. Those few companies which have made great gains by taking advantage of new manufacturing technologies did so by demonstrating top level leadership and man-

agement commitment. But far more prevalent are those top managers of manufacturing firms who are neither knowledgeable nor comfortable with their industry's equipment and process technologies. This is the major educational problem: the development of technologically competent and confident top management.

The great American industrial leaders of the past, such as Lowell, Singer, Carnegie, Ford, and McCormick, supplied *both* corporate and technological leadership. Today, the top management of American manufacturing is dominated by marketeers, financiers, controllers, and an extraordinary number of lawyers. Top management is not supplying adequate technological leadership. They do not have the judgment required to make large-scale investments in new equipment and process technologies which are calculated risks and seldom pay off in dollars for many years. The fact that production management courses are seldom included in advanced management programs or semii. contributes to the persistence of the vacuum of technology at top management levels.

Ultimately, we should see manufacturing people at the top again in reasonable proportions, but this requires further breadth and conceptual skills from manufacturing managers, attributes which are now the exception and not the rule. Meanwhile, the initiative for new manufacturing technology must come from manufacturing management because corporate attitudes at top levels often reflect technological illiteracy.

So we have an educational dilemma. Paradoxically, manufacturing managers need to acquire financial skills and learn to think in a competitive and strategic mode as effective top managers do, while top managers need the technological competence and confidence derived from experience and training in production. Until each acquires the other's strengths, their own individual strengths become in fact a corporate weakness, for in their work together they mutually debilitate and frustrate. Meanwhile, our industrial malaise goes on.

This situation can resolve itself, of course, in Darwinian fashion over a period of time, but the job of educators is to identify such problems and speed up the process. In the face of the problem, however, our present educational curricula for both engineers and managers have not only failed to identify and solve these problems, but contribute to them! By typically excluding manufacturing from top management courses and management education from engineering courses the problem gets compounded. Since the new industrial competition is fundamentally based on technology, our education of managers and engineers is too often failing the country's needs.

Part 3. Working Group Reports

The Issues and Some Answers: Recommendations of the Working Groups

The goal of the Symposium on Education for the Manufacturing World of the Future was to propose elements of an agenda that would revitalize and refocus manufacturing education and act as a catalyst for action by educators, employers, and practicing engineers. More specifically, in sponsoring this symposium the National Academy of Engineering hoped to encourage:

- Engineering and business schools to consider developing initiatives in manufacturing education;
- Companies to articulate their educational requirements for manufacturing professionals;
- Local, state, and national governments to examine their roles in supporting manufacturing education; and
- Schools and companies to reinforce cooperation in manufacturing education and research.

To these ends, symposium participants met in separate sessions to consider five diverse aspects of manufacturing education:

Structuring the Manufacturing Education System
Industry-University Cooperation in Education for Manufacturing
Industry-University Cooperation in Research for Manufacturing
Keeping Current in a Manufacturing Career
National Priorities in Manufacturing Education

The working groups acted as a forum for discussing present efforts,

identifying broader needs and opportunities, and "sounding out" new ideas and untapped opportunities for revitalizing and strengthening manufacturing education.

In addition, each group sought to formulate recommendations for action by both those who educate professionals and those who manage and operate manufacturing systems. The small group settings stimulated the flow of ideas for transfer of experience and practice between the factory and the educational system, while offering a way for both educators and manufacturers to articulate their needs and capabilities related to manufacturing education.

The following reports of the working groups were authored by the chairmen of the respective groups based on their perceptions of where agreement was reached and on what basis. Just as important, the reports also specify where no agreement was possible and articulate the basis for disagreements. Chairmen of the five working groups listed above were Robert Ayres, James F. Lardner, John Wilson, M. Eugene Merchant, and Jordan J. Baruch, respectively. The groups' members are listed in Appendix C.

Structuring the Manufacturing Education System

The technologies of manufacturing are changing in three ways that call into question the usefulness of current education for manufacturing. First, a revolution is under way in manufacturing systems, so that both process and discrete parts manufacturing will depend increasingly on a wide range of technologies such as computers, robotics, artificial intelligence, and flexible automation techniques. The underlying principles for these mechanisms are, however, traditionally taught in different engineering curricula, resulting in an educational format inadequate for the needs of those who will have to understand the new manufacturing technologies.

Second, the use of new materials in manufactured products may force extensive changes in manufacturing systems over the next 15 years. For example, the manufacture of large-scale integrated circuits, optical fibers, and ceramic engine parts will require a set of manufacturing skills significantly different from those needed to assemble the current generation of products.

Third, much of the economic potential of computers in manufacturing systems arises from their capability to establish an improved information flow between financial management and activity on the plant floor. Those who design and operate the plant floor, however, must be capable of designing and operating information systems that link the plant floor to the front office.

With these changes in mind, this working group was asked to investigate ways in which to establish and sustain an educational system in manufacturing engineering.

THE PROBLEMS AND ISSUES

Should the content and structure of professional education change in response to current changes in manufacturing technologies and organizations? After agreeing that the answer to this question is yes, the working group proceeded to discuss the design and implementation of a new educational system in manufacturing engineering and to answer such questions as: What institutional and financial resources are required for a viable program? What are the most effective ways to organize and implement a manufacturing education system?

Underlying this discussion was an issue of particular importance to group members from industry: What kind of manufacturing engineer will be needed in the future? This consideration raised a controversy within the group that was not resolved. Some members felt that universities should provide industry with educated individuals capable of evaluating alternative proposals, choosing the right vendor, and organizing maintenance and service. In other words, the educational product sought is not so much the individual who will design, adapt, or install a new manufacturing system, but one who is able to deal effectively with the specialized outside organizations that will design and maintain manufacturing systems in the future. Other members of the group felt that universities should provide a more fundamental knowledge of manufacturing processes which, with experience, will develop into the ability to select and implement effectively vendor-provided technology. The question certainly deserves further consideration.

Another unresolved controversy concerned the level of manufacturing engineering sophistication to be taught at the bachelor's and master's levels. It was not possible, of course, to evaluate fully the trade-offs that must be made between four- and five-year manufacturing curricula. The group did, however, recognize the trade-offs between engineering fundamentals and a manufacturing systems education per se, and theory and applications in engineering more broadly. There was general agreement that "systems integration" cannot be taught effectively below the master's level and that a wide range of fundamental skills needs more attention at the bachelor's level. In addition, undergraduate engineering students should:

- See manufacturing examples and solve manufacturing problems in traditional disciplinary coursework,

- Be exposed to system and product costing,
- Have some integrative, cross-disciplinary project experience,
- Have some experience working in groups, and
- Be oriented toward problem solving rather than rote answering.

It is probably fair to say that there is not any single best type of education for manufacturing. Different kinds of institutions will provide, of course, different kinds and levels of manufacturing engineering education; some will specialize in undergraduate training and others will focus primarily on graduate education. There is certainly room for two-, four-, five-, and six-year programs, but the group did not try to resolve how all these will fit together.

The group also tried to identify the unique core content of the manufacturing engineering discipline as opposed to other engineering disciplines. Perhaps 90 percent of the curriculum of a future manufacturing engineering educational system is already available from other departments, especially mechanical and industrial engineering, and to some extent electrical, chemical, and civil engineering. Is there then a critical 10 percent unique to manufacturing engineering, and if so, what is it? Or, stated differently: What underlying science content of manufacturing might serve as a basis for research? Again, the group was unable to resolve these questions, but most group members agreed that the primary research direction desired in manufacturing is that taken toward more cross-disciplinary "systems integration" work.

Finally, it was recognized that manufacturing engineering education will probably emerge at many universities as an interdisciplinary program at the graduate level, a likely direct result of funding for faculty research in manufacturing. At the undergraduate level, manufacturing engineering might initially surface through the addition of specialized coursework and projects to existing curricula in the departments of mechanical, industrial, and electrical engineering. Development of manufacturing engineering as a durable, separate engineering discipline will likely require convergence of these two trends.

RECOMMENDATIONS

The working group recommends that educators recognize that:

- Undergraduate students have a critical need for knowledge of manufacturing processes and process selection criteria, with emphasis on the process in the context of the overall manufacturing system.
- Undergraduate students have a critical need for implementation training beyond design problem solving, with special emphasis on producibility.

Although U.S. schools of engineering may emphasize problem solving more than schools in some other countries, problem solving, especially in design, needs more emphasis in undergraduate education. In particular, a greater focus is needed on integration between the design end of the problem and the manufacturing (or producibility) end of the problem. This feature is generally lacking in existing conventional engineering courses.

It is further recommended that educational institutions recognize that:

- All manufacturing students have a critical need for "people" skills, especially leadership and communication. Often missing in a conventional engineering education, these skills are probably best developed through project courses—that is, group projects in which students learn to accommodate one another, to cooperate, to subdivide problems, and to schedule.
- There is a faculty gap in integrative (i.e., process, design, and systems) and cross-disciplinary problem solving and a lack of focus on faculty development in these areas.

Finally, it is recommended that industry and government, including the National Science Foundation (NSF), recognize that:

- Since faculty development depends on availability of a critical mass of research opportunities, it is especially important that research monies be available to support interdisciplinary and integrative research.

Institutions develop in accordance with incentive structures. In universities, faculty development is driven by the availability of research funds in particular areas. Obviously, a very close connection exists between the recognition of interesting intellectual problems and the availability of funds, but it is often difficult to determine which comes first. In the case of universities, there will be no significant development of faculty capable of handling systems integration and developing manufacturing science unless funds are available for that specific purpose.

Funding agencies, and NSF in particular, prefer to support "bite-size" projects of $30,000-$50,000 and provide support for perhaps one graduate student per year. It is true that some projects have longer life—two- and three-year projects are possible—but these are increasingly scarce. Under these circumstances, it is unlikely that a proposal to develop a science of manufacturing, integrating factors at all levels of aggregation and involving a number of different disciplines, would survive the existing peer review processes.

Industry-University Cooperation in Education for Manufacturing

In a field as industry-dependent as manufacturing, it is imperative to establish and maintain strong ties between universities and industries. Cooperative programs in engineering education, combining classroom studies with intervals of industrial experience, have existed since early in this century. In many industries and regions of the country, however, these close ties have not existed in the manufacturing area.

Over the last few years, initiatives have sprung up in university-industry cooperation in numerous fields, particularly in high-growth fields with strong commercial interest such as biotechnology and microelectronics. Recognizing needs and opportunities in the area of manufacturing, several firms and universities have experimented with new forms of industry-academia cooperation, going well beyond traditional concepts. For example, innovative programs have been launched at such schools as Lehigh, Rensselaer, and Carnegie-Mellon, and the IBM Corporation has fueled the challenge to universities to increase their efforts with grants for program development in manufacturing systems engineering. Added impetus has been provided by new state and federal programs; one example is the Engineering Research Centers of the National Science Foundation.

The task of this working group was to assess the benefits and perils of such programs, to highlight successes, to propose ways to reduce obstacles to future successes, and to provide a realistic assessment of what university-industry cooperation in manufacturing education might achieve. This task also meant seeking answers to related questions such as: What sequence of events is necessary to establish industry-university cooperative programs in education? To what extent do facilities and infrastructure account for inadequacies in university-based education for manufacturing?

THE PROBLEMS AND ISSUES

General Issues

A number of general issues in industry-university relations set the context for cooperative efforts in education for manufacturing. First, there is the lingering mutual suspicion arising from the different cultures and, to some degree, the different value systems that industry and university represent. In the 1960s and 1970s, university-industry relations were not only suspect, they were often adversarial.

Second, even as we are moving toward a much more sympathetic atmosphere between the two communities, practical considerations such as time frames and resources still tend to inhibit cooperation. The time frames of planning and operations are far different in industry and universities. A university typically takes the long-term view, which is appropriate to education and the search for the advancement of human knowledge. Industry, however, must focus primarily on real-time, immediate problems. A distinguished university expects to live forever; the life of a firm is much more perilous. While in some ways universities are more stable, they are also weaker in some respects. Research resources of both industry and universities are limited, but they are especially limited on university campuses.

Third, related to the questions of time frames and resources is the issue of sustained participation. Frequently, criticism is voiced that industry support is not stable enough. Because of the nature of commitments to students and to faculty, a longer time frame is required on university campuses in terms of support and funding than in the more flexible year-to-year planning of industry.

A fourth issue concerns attitudes toward knowledge and information. Industrial firms tend to think in terms of proprietary information, while universities encourage and defend the free flow of information. For some collaborative efforts between industry and academia, concern about proprietary information may be a serious obstacle to success. Overall, experience suggests that it is an exaggerated and a diminishing problem, but it still exists and provides an excuse for avoiding closer cooperation. It is much less demanding to argue about how to handle proprietary information than it is to find ways to promote cooperation between industry and universities.

A fifth issue is the problem of the science and engineering language as it is used in both cultures. Although everyone supposedly speaks the same language, each uses it differently. Differences in what words mean and how terminology is used create barriers to industry's and universities' understanding of one another's problems. As the relationship grows between the two, the need for translation and interpretation will diminish. At present, however, a large part of time spent together is still used to establish a basis for effective communication.

Finally, there is a basic problem of differences in incentive structures, and the fact that industry and university people dance to rather different tunes. Universities tend to recognize and reward individual achievement and promote heterogeneity, while industry places greater emphasis on group achievement, material rewards, and homogeneity.

Although none of these differences between industrial firms and

universities is likely to change significantly, a tremendous benefit can be realized by increased cooperation between these two kinds of institutions. Existing examples of successful cooperation leave no doubt that relations can be improved locally and in aggregate at the national level, perhaps by a quantum amount. The key is to focus on specific programs and provide specific incentives so that barriers to cooperation are minimized. Universities are certainly ready to participate as evidenced by the vigorous and widespread responses to the new Engineering Research Centers program of the National Science Foundation and the program for manufacturing systems engineering curricula sponsored by IBM.

A Specific Issue

In discussions of education for manufacturing, one oft-heard, emotional issue concerns the perceived low image and status of the manufacturing engineer (or any engineer who deals with manufacturing problems). Industry and universities perceive the excitement and challenge of manufacturing quite differently, although even industry is far from universally supportive with rewards, money, and responsibility. Certain steps can be taken to increase the prestige of engineers involved in manufacturing, both in industry and on the university campuses, including perhaps widely publicized statements—encouraged by the National Academy of Engineering—that, indeed, manufacturing has changed. The message should take an appropriate form and be delivered from selected platforms by industry leaders, university leaders, and the Academy leadership. It should reach not only a general audience but also the schools of business and management.

Representatives from industry will not change universities by going on campus and telling students or faculty about the marvels of manufacturing today and the challenges it represents. As Robert Cannon (in this volume) points out, a "conversion of faculty interest" must be based on faculty understanding of what is the best manufacturing practice industry has to offer, what is needed, what the problems are, and what kind of intellectual challenges and career opportunities manufacturing represents. There is a persuasive argument for converting the faculty first because in terms of total student exposure (ranging from college freshmen to graduate students working on thesis projects), faculty members, not the occasional campus lecturer, have the greatest opportunity to influence students. A student's summer work experience in industry is seldom equal to faculty influence.

RECOMMENDATIONS

National Faculty Advanced Training Program

Discussion about recent advances in manufacturing and the need for diffusion of knowledge about these advances led to an intriguing and exciting idea: establishment of a national faculty advanced training program in manufacturing. This concept, which is not as elaborate or as complicated as it may sound, will give university faculty an opportunity to learn firsthand why manufacturing is exciting, why it is a challenge, and how it has changed. Thus this working group recommends that:

- Individual companies arrange to conduct one-week manufacturing seminars for 20-30 engineering and business faculty members at a time. Possibly held in the summer period when faculty can commit themselves to attend for a week, these seminars should be a high-quality presentation of the nature and the problems of manufacturing. More specifically, seminars would elucidate why university professors should be aware of what is going on in manufacturing and why their students might wish to seek employment in this area. Expenses for seminars would be covered in part by the sponsoring companies. Incentives for companies to support this activity include the opportunity to influence the education of future employees.

What might help define and encourage such a seminar program in manufacturing and give it coherence? It is recommended that:

- The Academy complex consider taking a leading role in fostering this program and creating both its substance and structure.

Because of the varied nature of manufacturing activities in the United States, there appears to be a need for the careful and thoughtful design of regional seminars. Travel distances may impede attendance for some people and subsequent cooperation between companies and universities. For example, it seems foolish to hold a seminar on chipmaking in the Silicon Valley for faculty surrounded by midwestern metalworking industries where the only chips are metallic shavings. The programs of advanced training seminars should continue for three to five years, or until they have reached a significant percentage of all engineering and business school faculty in the United States.

Manufacturing Curricula

Both academia and industry question the pertinence and realism of what is being taught in engineering schools. With the exception of

certain areas of engineering research, the problem is widespread in areas dealing with manufacturing.

Are engineering faculty members becoming too theoretical and too analytical? Could it be that one generation of analysts is teaching a second generation of analysts who in turn will teach another generation of engineering faculty, and yet none of them will have ever even manufactured anything secondhand? Although this group did not reach a full consensus, it was concluded that the present situation is not too bad. An analytical capability is expected from universities and a practical hands-on capability from industry. These two groups may not be fluent in each other's language and may not fully understand each other's problems, but they have the skills, knowledge, and experience which, when put together, can become a powerful resource for improving productivity and the competitive position of U.S. industry.

How then can efforts in the university world be brought closer to current manufacturing practices and problems? One possible strategy is the use of industry advisory boards. When properly chartered and directed to offer broad guidance on content and direction of education and research, they can be very helpful. In addition, individual practicing engineers can serve on campus in more ways than simply as guests who appear occasionally as role models for students. They could, for example, assist faculty members with problem and project definition.

The traditional cooperative education (co-op) programs and senior projects are also valuable ways of stimulating exchanges between industry and the university community. Co-op programs can open to young engineers vistas not accessible in any other way. Fortunately, co-ops are widely recognized as beneficial and are a part of many strong educational programs. They lend themselves well to a manufacturing-related education. Unfortunately, senior projects are disappearing simply because no funding and no faculty are available to support such projects. Senior projects are one of the most expensive undergraduate activities and thus are the most vulnerable to budget cuts. Yet, these projects are a superior means of bringing together the various disciplines of engineering into a comprehensive whole.

A properly designed senior project provides the integrative environment that industry finds lacking in most engineering schools. Efforts to reinstate senior projects into the curriculum as part of an engineering education relevant to manufacturing should be encouraged.

This working group also found that too frequently the team nature of manufacturing is neglected in the university environment. Group activities should be an essential part of the manufacturing curriculum.

The manufacturing problems studied on the campus may not be realistic, but the human relations problems that arise in multidisciplinary efforts certainly can be!

While it is important that universities have a certain amount of modern manufacturing hardware in their labs, no university can afford to have its own modern factory. Thus alternative means are required to provide a real picture of the complexity, breadth, and depth of manufacturing, starting with product design and ending with a manufacturing operation servicing the product in the field. Computer models, for example, can portray some of the real complexities of manufacturing. Via simulation, manufacturing problems can be relayed to university campuses; they do not require manufacturing hardware for learning and for research. However, real data must be put into the model—and that industry should be able to supply.

Video is an another important means of conveying realistic images. The technological capabilities are available to make video real-time and interactive. Universities and firms should exploit video technology further to extend the effective size and extent of university laboratories.

The ferment currently under way in manufacturing-related education raises then a number of questions: Is there a single best model for a curriculum? Should there be a strictly prescribed manufacturing engineering curriculum? Should it be only a graduate program? Should manufacturing be an option within existing degree programs? Should it be developed as an autonomous, separately accredited program?

This group concluded that, given the diversity of industrial sectors and geographic regions of the United States, the rapidly evolving nature of industry and its problems, and the various levels of sophistication in the current industrial environment, the response to this challenge demands a pluralistic approach. Moreover, action on several levels in the educational system is necessary. It is unrealistic and unwise to propose a national, standard curriculum. Rather, it is more feasible to build on the strengths of each university and region and provide opportunities for addressing manufacturing in a variety of ways.

While this is a time for diverse experiments by individual institutions, good opportunities for initiatives by groups of firms and universities probably exist as well. Such consortia could be a particularly useful mechanism for firms and schools not having large resources. In fact, some larger firms may prefer to develop or expand in-house programs of postgraduate education for engineers. For smaller firms, more extensive university training programs may be the only practical solution.

Finally, it would be useful for an organization with wide contacts to create and operate a clearinghouse for information on successful initiatives in industry-academia cooperation in manufacturing. Thus, rather than starting from scratch, new programs in a given region or industry can be modeled after a successful existing program.

To summarize the findings of this working group, it is recommended that:

- The overall university-industry dialogue be enhanced to establish a spirit of cooperation in the common interest of the country.
- Specific incentives be used to minimize the importance of what will be abiding differences between universities and industry.
- Vigorous efforts be made to convey the excitement and importance of the new world of manufacturing.
- An intensive program be established to share current industrial practice and problems in manufacturing with engineering and business faculty.
- A range of mechanisms be used to improve the relevance and realism of on-campus manufacturing education.
- Innovative, cooperative, and economical means be used to expose students and faculty to the factory floor.
- Diverse experimentation be undertaken at a variety of educational levels with manufacturing curriculum.
- Experimentation be undertaken with cooperative institutional mechanisms.

Industry-University Cooperation in Research for Manufacturing

Experience suggests that the subject matter of commercially useful research and the time frame within which a firm would like to see results do not always agree with university practices. In the field of manufacturing, more advanced research is going on in many firms than at most universities. In fact, within many universities the study of manufacturing technology is not customarily part of the research program.

This working group examined both the forms and the content of industry-university cooperation in research for manufacturing. These forms range from traditional research agreements and faculty consulting to more novel arrangements such as centers for manufacturing research. From an industry standpoint, these forms are potential vehicles for advancing industry objectives through the transfer of commercially useful technology.

This working group also explored arrangements that promote cooperative research and the obstacles encountered. Participants in such arrangements include the firms and schools likely to undertake cooperative research projects and the state and federal agencies possibly able to facilitate them.

THE PROBLEMS AND ISSUES

The need for a better exchange of information, more than new solutions, was the main theme arising from discussions about industry-university cooperation in research for manufacturing. Investing money in research relationships without a mutual understanding of the reward system and the pressures faced by both parties brings little progress.

Initially, universities need to know where to get information about industry research requirements, while industry needs to know more about the research activities and capabilities of universities. Regarding the latter, potential industry collaborators are often baffled by university politics; others may be put off because there is no visible place at many universities to "plug in" to research on manufacturing issues. In some cases, an industry with a well-defined research agenda will be unable to find universities interested in its kinds of problems. The Society for Manufacturing Engineers, the National Technical Information Service, and the National Science Foundation can be helpful in identifying and locating the potential relevant institutions and individuals.

Are there ways in which to facilitate the real investment in time and energy required to start and maintain a productive research relationship? A serious commitment to cooperation by both university and corporate managers is needed. This requires, on the one hand, more enlightened university administrations, necessitating changes in compensation, promotion, and tenure. On the other hand, firms must realize that cooperation with universities should be a serious management objective. Encouraging and developing entrepreneurial talent at universities will help bring the two groups together as well.

Key factors relating to cooperative research arrangements include government incentives, ranging from grant-and-aid programs to tax legislation, as well as legal constraints on both sides that concern proprietary information and other matters. Another factor is access to the "research market." Many firms are accustomed to dealing with suppliers and consulting firms, but not with the academic research community. In this vein, industry representatives contrast the "commitment to deliverables," which characterizes industry research, to

the "best effort," which is standard in university research contracts. University personnel need incentives to engage in useful research. Incentives could include more refereed journals, more dollars for awards for young scientists, a more active exchange between industries and universities, and more support for co-op programs.

RECOMMENDATIONS

This working group recommends that:

- A message be transmitted nationally on the seriousness and high priority of the manufacturing problem.

The high priority of and potential for joint efforts by the university and industry research communities in manufacturing must be well publicized at both the university and industry levels.

- A better data base be compiled on current activities in manufacturing research.

There is a strong sense that industry is unaware of a wealth of resources existing in the various technical departments of engineering colleges. A better system of exchanging information would enable representatives of an individual firm or an industry association looking for help in a research effort to know where to go.

- The need for more aggressive participation by academia in manufacturing research be publicized.

This message has to be transmitted generally and translated into practical and specific terms of where constructive things can be done. Today, the usual transmission of the message about manufacturing in the press is, "Company 'X' has gone out of business because of external competition," with few proposals offered about constructive responses.

- Some accounting methods be addressed.

As a practical matter, firms take research efforts seriously only when they understand the actual bottom-line benefits. Over the long term, this means that as university-industry consortia are promoted, the engineering division of the university and the business schools should both be involved. Group members differed on how that involvement should go forward, but they did agree that if the people who will undertake the financing, accounting, and management of manufacturing and manufacturing research are not engaged, a serious aspect of

manufacturing technology implementation, from industry's point of view, will not be considered.

- More government funding be sought for existing manufacturing research programs.

The manufacturing problem is a systems problem. The use of a systems approach to manufacturing to solve the systems problem should permeate all research activities and research results, but it is a larger problem than some individual industries can tackle. Since the needs for such research projects and facilities often extend beyond university-level regular funding, the national interest clearly dictates that existing manufacturing research programs remain fully funded, enjoy a regular growth in appropriations, and develop cooperatively with industry.

- Tax incentives continue to be improved for university-industry cooperation, particularly with regard to research.

The jury is still out with regard to the effects of such tax incentives on research spending. Anecdotal evidence, however, suggests that the incentives are effective, and that additional incentives would also have a marked and positive result.

- Manufacturing engineering research be funded at an early point, as curriculum changes at engineering schools usually follow from research projects being undertaken by individual professors.

Usually, a critical mass of research is required to generate material that can be taught to students. Thus, if manufacturing engineering research is adequately funded, curriculum development will come automatically.

- A more well-developed theoretical basis for manufacturing—one that encompasses a systems approach—be devised.

Keeping Current in a Manufacturing Career

Those who work in manufacturing usually find it neither appropriate nor possible to become a full-time student or a full-time educator. The obligations of family and career and the costs of tuition make it untenable for most people to break away from their present job without severely disrupting both their professional and personal lives. Yet these manufacturing professionals are being inundated by information on new technologies that eclipse the production processes they know well, management practices that challenge all the lessons they were

taught, and investment decisions that defy evaluation by the standard techniques.

For the ranks of manufacturing professionals—that is, the engineers, managers, and finance officers who make decisions in a manufacturing firm—keeping current in their manufacturing career is crucial if they—and their firms—are to prosper in the manufacturing world of the future. Only easier access to more educational opportunities in more flexible formats at a lower cost per student will permit manufacturing professionals to harness the potential of the new manufacturing technologies, make and sell quality products, and have a satisfying career all the while.

This working group examined the manufacturing career by seeking answers to three questions posed in its charter: (1) Why does anyone go into manufacturing as a career? (2) How does one maintain the vitality of a manufacturing career? and (3) What is needed in a continuing education program adequate to serve the diverse needs of manufacturing professionals?

THE PROBLEMS, ISSUES, AND RECOMMENDATIONS

Without continuing education, our national manufacturing capabilities and excellence will decline. It is not only a question of keeping current, but also one of becoming current. The recent rapid rate of change in manufacturing has created a large group of manufacturing professionals whose skills have been made obsolete. Thus this working group addressed the issues involved in bringing these individuals up to speed as well as keeping those who are current in that state.

Correcting a Poor Image

In undertaking its mandate, the group defined the critical issues and the actions needed to resolve the three questions posed earlier. The first question, however—"Why does anyone go into manufacturing as a career?"—was immediately changed to "Why don't more first-class engineers go into and stay in manufacturing careers?" It is not only a question of getting into a manufacturing career; it is also one of staying in that career. The working group felt as well that the original question implied that only runners-up go into manufacturing careers.

A review of the range of contributing factors pointed to one obvious critical issue: in this country, manufacturing has a poor image and manufacturing careers have a poor status. To upgrade this image, industry (both individual firms and industrial associations) and profes-

sional societies must share the excitement of today's manufacturing. Potential candidates for engineering careers must hear more about the "action" in manufacturing today, and primary and secondary school teachers, as well as the general public, must be aware that real and significant career development opportunities exist in manufacturing.

Industry needs to take one further action. Firms must bear witness to the value of the present manufacturing personnel and structure good professional career paths in manufacturing. Furthermore, these developments should be publicized to all current and potential employees to let the community at large know that real professional career paths and opportunities exist in their company for manufacturing professionals.

Staying Current

How does one maintain the vitality of a manufacturing career? Manufacturing engineers face the same threat of obsolescence as all engineers, but keeping current in a manufacturing career in this time of rapid change is even more difficult than usual. Some engineers seem to resist adjustments to new technologies, but most wish to stay current and yet are unaware of how to go about it. In examining the incentives for both employers and individual engineers to stay current and the role of employers in providing such, it became evident that having the incentive to keep current is just as important as the availability of continuing education.

This observation raises two issues. First, employers fail to evaluate the educational needs of manufacturing professionals to identify the skills or education they lack. An excellent prescription for doing just that is presented by Robert M. Anderson (in this volume), and this working group endorses his prescription. It thus recommends that:

- Employers use Anderson's prescription as a basis for this evaluation, being very certain to involve the engineer in the evaluation.

It is crucial that such an evaluation not be "management only" and that the engineer participate in identifying gaps and how they should be filled. Subsequently, the company must follow through and work with the professional to fill the identified gaps.

The second issue is that many manufacturing professionals lack a sense of responsibility about the need to maintain the vitality of their careers in manufacturing. This attitude, however, is not totally the fault of the professional; generally, he or she has had no incentive to feel this sense of responsibility. More often than not, the individual

has moved out of manufacturing to advance his or her career or to maintain professional vitality. Thus it is recommended that:

- Industries, universities, and professional societies provide realistic incentives for professionals to maintain the vitality in their manufacturing careers. These incentives should include existing incentives such as certification.

For example, the Society of Manufacturing Engineers offers manufacturing engineers a series of examinations to acquire certification voluntarily (see Brummett, in this volume), and such programs may merit greater recognition from industry as a real measure of competence in the field. Clearly, greater recognition of certification as a measure of professional competence and support for those who pursue it will serve as a real incentive for an engineer to become and to stay certified.

Other incentives to keep current might include tuition support or release time to attend continuing education activities. It is recommended that:

- Further innovative incentives be sought to encourage professionals to maintain the vitality in their manufacturing careers.

Continuing Education

What is needed in a continuing education program adequate to serve the diverse needs of manufacturing professionals? This question touches upon a number of diverse issues, for example: the different needs of the chemical versus the electronics industries; whether the employees of larger manufacturing firms have an advantage over the employees of smaller machine shop-scale firms; the value of full-time continuing education courses versus intensive short courses; and the value of the "nuts and bolts"-type courses now available.

Consideration of these issues led to two observations by the working group. First, in firms where continuing education for manufacturing professionals is a recognized priority, the demand for such education quickly outstrips the ability of the firm to either develop the courses in-house or support course attendance elsewhere.

Second, manufacturing professionals need an opportunity—not now available—to take "refresher" courses in the scientific and technological principles newly important to manufacturing applications. Only by understanding the flow of changes taking place around them can they contribute to making those changes happen and learn to innovate within the integrated system.

Despite these insights, the provision of continuing education remains a problem of substantial proportions across the spectrum of manufacturing industries. The key issue is that there is no system for continuing education for manufacturing professionals equal in scope and effectiveness to that existing for entry education into manufacturing careers through the university system. Thus it is recommended that:

- The National Academy of Engineering or the Manufacturing Studies Board of the National Research Council conduct a study to define a system for the continuing education of manufacturing professionals. Such a study should involve strong industry participation, including industrial associations, as well as the participation of professional societies, universities, service organizations, and other educational agents.

For a successful study, industry must specify early in the process the features it perceives as needed for a continuing education system. These can then be debated and refined and the study can define and structure a system having the desired features. Clearly, no one of the groups listed in this recommendation can by themselves define and operate a continuing education system. The system and the study must include all these groups to be effective.

National Priorities in Manufacturing Education

Education for manufacturing has not been a social priority in the United States for the past quarter century. As a result, the number of manufacturing education programs has remained very small, and the prestige of being either a student or an educator in manufacturing has been similarly small.

In the face of increasingly proficient international competition, concern for the quality, prestige, and extent of manufacturing in the United States has risen to the forefront as a technological and social priority. Consequently, many new university programs will be established across the country over the next several years. Many people, however, have questioned whether new university programs are either an appropriate or a sufficient response to the national need for increasing manufacturing expertise.

As the use of new manufacturing technology transforms the profile of skills needed to operate and manage a factory, job definitions and work structures will evolve as well. It is still an open question whether more skilled, less skilled, or differently skilled people are needed. At

this stage of the national wave of manufacturing education development, it is important to consider whether the programs in operation and the programs on the drawing board will be appropriate to national needs a decade or two from now.

The task of this working group was to speculate on the types and number of programs needed, their value in the spread of new knowledge, their accessibility for working professionals, and their ability to adapt to the continual change certain to take place in manufacturing and information technologies until the next century. The recommendations of this group were addressed to federal, state, and local agencies who fund and regulate education programs; prospective students who must have better information about the manufacturing education options available; and any organization that is considering setting up its own manufacturing education program outside of a traditional university curriculum.

THE PROBLEMS AND ISSUES

In arriving at a set of national priorities in manufacturing education, the group began by attempting to define manufacturing engineering, how one learns it, and what this involves. Group members—representing academia, government, both sides of Congress and the executive branch, industry, consumers of engineering, and suppliers of engineering—recognized that everyone participating in manufacturing engineering is having a problem.

The working group generally agreed that manufacturing engineers must have a thorough grounding in fundamentals. With this background, they are then able to shift their activities as changes are made in technology, in the demands on the manufacturing system, and in the potential for manufacturing. More and more the task of manufacturing involves not just unit processes or manufacturing elements, but also manufacturing subsystems and systems, and these pose some very special problems.

Engineering schools in general have an adequate number of applicants, although few overall in manufacturing engineering. Furthermore, the quality of the students and the general health of engineering education seem good. Many schools are initiating programs in manufacturing engineering, but they are facing problems.

One problem identified quite early by the group is that a good faculty member in manufacturing engineering is an asset not only to a school but also to a manufacturing company. Therefore, perhaps more than in other fields of engineering, the schools and the industry are faced

simultaneously with the tasks of competing and collaborating—a conflict that must be resolved.

A model for the clinical practice of manufacturing engineering can be based in part on that used for the clinical practice of medicine. Much of the underpinning for the modern clinical practice of medicine in the United States stems from the support, direction, and intellectual involvement of the National Institutes of Health (NIH). For manufacturing, there is no equivalent to NIH in the federal, state, or local governments despite the fact that manufacturing is as much a profit-making, private enterprise as the physician's health care practice. In manufacturing, too, there are strong reasons for society to participate in ensuring excellence in the United States, ranging from jobs created or saved to the central role that manufacturing plays in establishing both a standard of living and quality of life, our defense posture; and even our national pride.

RECOMMENDATIONS

Based on a strong consensus that society, in addition to the companies involved, has a stake in the excellence of our manufacturing enterprise, the group recognized that a mechanism is needed so that society can share the cost of developing the resources necessary for excellence in manufacturing. It is therefore recommended that:

- The National Science Foundation, which in Fiscal Year 1985 has only a $7.5 million budget for manufacturing, significantly increase its funding for the support of manufacturing engineering.

Just as NIH has the resource of the teaching hospitals, an equivalent is needed in industry. It is therefore recommended that:

- A national priority be industry-university collaboration to assure the relevancy of research and the availability of industrial facilities for manufacturing education.

This collaboration can be exercised through the National Association of Manufacturers, the U.S. Chamber of Commerce, and other organizations influential in industry. This does not mean that industry directs the research and education; only that closer collaboration can acquaint faculty and students with industry's problems, particularly with those of the future. Research and education start to pay off especially when oriented to anticipated future developments.

Salary disparities between academia and industry are a major issue within the profession nationally. For example, an assistant professor

in manufacturing engineering today may earn $27,000 a year, while his counterpart in industry may earn 50 percent more. It is recommended that:

- Steps be taken, with the help of industry, to either provide funding to make up that differential or create a system of side employment or a program that will permit qualified industrial manufacturing professionals to serve as faculty members in the universities.

The primary value of research in manufacturing engineering is to the industries themselves. It is therefore recommended that:

- Industry sectors work out mechanisms, as they have in some specialized fields such as semiconductors and petroleum refining, to provide adequate nongovernmental sources of funding for research and other manufacturing-related activities at universities.

A bill submitted in 1984 to the U.S. Congress (Senate 1286) to support manufacturing delegates a set of research activities to the Department of Commerce. This working group believes it is appropriate for the National Academy of Engineering to suggest such legislation. It is also recommended that:

- The National Academy of Engineering use its charter to take an aggressive posture to encourage implementation of government policies that support manufacturing research, education, and related activities.

The need for an education for engineers and others involved in manufacturing does not stop at the university gate. In fact, productive learning continues after engineering students are employed by industry, and particularly when they participate in a program of continuing education. In much the same way, finance officers, personnel officials, and corporate lawyers should as well broaden their knowledge of manufacturing to increase the nation's competitiveness. Unfortunately, recent changes in the tax law reduce the incentives for engineers and other professionals to pursue an education to broaden their base or to extend their knowledge in the field of manufacturing. It is therefore recommended that:

- The tax law be adjusted to give professionals in manufacturing, whether they be engineers, managers, or finance officers, incentives to pursue continuing education and to broaden their background in manufacturing.

Many in our society are unfamiliar with technology. Many younger people have no idea of the relevancy of technology to their life and

rarely know how the things they take for granted are made. It is therefore recommended that:

- The Commerce Department be encouraged to establish a program for the public's understanding of technology, including manufacturing, in collaboration with industry and the media. This program should emphasize educational activities for students, from primary school children to high school seniors.

This program could, for example, arrange for primary school children to see how bread is baked on a mass production basis, or urban children could visit a farm to see the amazing amount of technology being used today. Many young farm people are already familiar with farm equipment, but they may not be acquainted with a new factory to generate alcohol from corn. Such a factory is becoming an important factor in determining the price of corn, and it uses some innovative technologies. For example, in one factory even the carbon dioxide and excess heat are used to grow lettuce hydroponically, at a rate of 20,000 heads a day. The National Association of Manufacturers could also encourage its members to host visits and tours of their plants for primary and secondary school students.

Finally, it is critical that students at all stages learn why mathematics, physics, and other sciences that underlie manufacturing are important and appreciate their value in everyday terms. Students should graduate from secondary school with an understanding of the role and essence of manufacturing in our society. This would encourage students to recognize manufacturing as a possible field of study in their university program. It is therefore recommended that:

- A concerted effort be made to demonstrate to state and local boards of education that familiarity with manufacturing processes is an important component of both primary and secondary education.

Appendix A

Statement of the Manufacturing Studies Board on the Need for Industrial-Academic Cooperation for Manufacturing Technology

In the past decade, the economics of manufacturing have changed dramatically. Manufacturers are seeking new ways to build capacity that will increase flexibility, thereby increasing productivity and improving the ability to respond to worldwide competition. Many high-technology manufacturing innovations—computer controls, computer graphics, robots, and others—have provided attractive opportunities to raise productivity and meet new marketplace needs.

Despite such dramatic technological advances, U.S. industry is only slowly adopting the new manufacturing technologies. The reasons for this include a shortage of knowledgeable personnel who understand the implications of the ability of new technologies to respond to business needs, and a scarcity of manufacturing research at the university level.

The evolution of this situation is not hard to trace. Historically, companies met the need for manufacturing engineers by promotions from the ranks of machine operators. Manufacturing engineers were generally separated from the rest of the organizational hierarchy. Engineers on their way to the top might be rotated through design, sales, or even finance, but seldom through manufacturing. In fact, until recently manufacturing technology was not generally considered

The Manufacturing Studies Board of the National Research Council is chaired by George Ansell. This statement was originally developed for this symposium by a subcommittee chaired by Roger N. Nagel. Irving Bluestone, Robert H. Elman, Daniel Berg, Erich Bloch, Donald C. Burnham, and Wickham Skinner served on the subcommittee.

a critical element in an organization's financial or marketplace success. Without an expressed demand for graduates proficient in "factory floor" sciences, universities did not feel the need to direct resources toward manufacturing issues.

Thus, in the relationship between the industrial and academic communities—essential to maintaining technological excellence in high-technology industry—there has been a tendency to neglect manufacturing technology and its supporting sciences. Consequently, by 1980 fewer than half a dozen universities offered specific manufacturing engineering degrees. In most U.S. universities, manufacturing issues have not been in the mainstream of engineering and business school curricula, with the result that only a few graduates of these schools go into manufacturing jobs.

The tide may be turning, however, as evidenced by the interest in this symposium. Further, a study by the Manufacturing Studies Board has found many new cooperative arrangements between companies and universities started in the past four or five years. The National Science Foundation's Engineering Research Centers program is another hopeful sign.

Several barriers to improving the relationship between the industrial and academic communities remain, however. For example:

- *Equipment*. Three factors are at work here. First, although modern manufacturing equipment is vastly more productive, it is also substantially more expensive than that of the previous generation and requires a level of maintenance that is sometimes a financial hardship for academic institutions. Second, modern manufacturing science is increasingly systems oriented. This means that manufacturing cells made up of a number of different machine tools working within a single system are becoming the norm, and a single stand-alone machine tool is no longer valuable as a teaching aid. Third, the rapid advances in manufacturing technology impose substantial updating costs on any university wanting to teach manufacturing sciences with state-of-the-art equipment.

- *Experience*. Because manufacturing science is applications oriented, there is an urgent need for teaching faculty with hands-on manufacturing experience. It is difficult to find such faculty because (1) tenure practices inhibit academics from leaving their posts to gain such experience, and (2) degree requirements and salary considerations inhibit industrial manufacturing engineers from joining university faculties.
- *Proprietary knowledge*. If a firm develops a solution to a manu-

facturing problem, it will use that solution to gain a competitive advantage rather than share the knowledge with its industry. This conflicts directly with the academic institution's need to disseminate knowledge and publish research.

- *Curriculum development*. Because manufacturing science encompasses many different disciplines—including computer science, logistics, materials science, and industrial engineering—the ideal university curriculum from the manufacturers' standpoint will include courses in both the pure and applied sciences. The development of such a curriculum requires close coordination among diverse university faculties; some universities have had difficulty achieving such coordination. Equally important to curriculum development is the manufacturing community's articulation of problems and opportunities that will have to be addressed by manufacturing engineers entering the factory.

- *Lead times* (the period required from the time a decision to make a product is made to the beginning of actual production). Typically, the viewpoint that manufacturing firms bring to technological issues is more short term than that of universities. University research on specific technological issues often does not move fast enough for the needs of a manufacturing operations manager. In addition, it is unlikely that the traditional slow response by universities in developing manufacturing science laboratories and faculties would meet the more immediate needs of the industrial manufacturing community.

Many of these barriers are being recognized and attacked. Several experiments now under way, both in the United States and abroad, show promise as models for industry-university cooperation in manufacturing sciences. Until these and other examples can be given substantially greater exposure, however, it will be difficult, if not impossible, to draw useful lessons from them.

The consequences of neglecting basic research and education in the manufacturing sciences could be catastrophic for the United States. The country's experience in basic industries such as steel, automobiles, and machine tools demonstrates that engineering talent and basic research are vital to the international competitiveness of the nation's economy. Close cooperation between U.S. educational and business leaders is required to prevent the United States from becoming a "second-rate power" in the manufacturing sciences. Through cooperative efforts between U.S. industry and academia, a new generation of engineers will be trained, capable of wisely using the manufacturing systems of the future.

Appendix B

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